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# Enhancing science literacy through implementation of writing-to-learn strategies: exploratory studies in high school biology

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Enhancing science literacy through implementation of writing-to-learn strategies:

Exploratory studies in high school biology

by

Liesl Marie Hohenshell

A dissertation submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Major: Education

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For the Major Program

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*If I knew all about this one thing, wouldn't that be something...*

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To the force beyond the realm of science, may the arrogance and in particular, the selfishness this work represents subside. If I have achieved some level of success in coherently communicating some general understanding of what for me is largely still developing, I am grateful for the time I was afforded to construct and represent this. As with Emig, "writing is self-rhythmed. One writes best as one learns best, at one's own pace" (1977, p. 126).

## CHAPTER 1. GENERAL INTRODUCTION

Authors and researchers working within the writing-to-learn movement suggest that language creates, describes and reflects existing ideas and understandings (Keys, 1999b; Halliday & Martin, 1993; Lemke, 1990). For the writer, the act of writing promotes attainment of personal meaning, processing skills, requires thinking, and offers an opportunity for reflection on content (Applebee, 1984). Through writing, a student can demonstrate significant effort and communicate understanding of content. However, the promises of writing as powerful learning mode are manifold; and the practices and strategies used to reach such potential, appear to be equally as complex. The purposes of the enclosed papers were to reveal some of these dimensions, and make modest empirical contributions to a growing research base, which seeks to advance understanding of some of these dimensions.

### Introduction

Recent editions of instructional texts for science teachers encourage the use of a variety of writing tasks, but provide little to no guidance or direction, presuming that students have the rhetorical knowledge and procedural strategies to succeed in writing and learning by engaging in these types of tasks. Literacy may imply a need to write (Norris & Phillips, 2003); however, alternative conceptions exist concerning what literacy in science means (Laugksch, 2000). While there are various models describing the cognitive processes involved in writing that may contribute to learning, research on writing to learn has failed to establish definitive links to science learning as a result of writing (Klein, 1999; Rivard, 1994; Rowell, 1997; Schumaker & Nash, 1991; Ackerman, 1993; Holliday, Yore, & Alvermann, 1994). The type of task and its exigency are thought to evoke different cognitive processes, which may result in a different kind or *quality* of learning (Langer & Applebee, 1987;

Newell, in press; Schumaker & Nash, 1991; Tierney, Soter, O'Flahavan, and McGinley, 1989). Thus, there is a need for more research to determine the effects of particular kinds of tasks on student learning (Applebee, 1984).

While there is general agreement that writing, as an isolated act, will not necessarily result in learning (Klein, 1999; Rowell, 1997), a need remains for more empirical research linking learning outcomes to writing and describing the pedagogical contexts in which these tasks are situated. The particular strategies that support learning through writing as well as the role of the teacher in facilitating learning when implementing these strategies need to be further explored. The factors students engage in during the process of writing about science concepts should also be investigated to identify whether any in particular contribute to students' success in writing and learning.

#### Research Questions

The overarching research question framing these studies centered on establishing particular distinctions between traditional and non-traditional writing tasks and routines in terms of how these strategies facilitate learning through writing. The issues arising from the various theories and studies explored in the literature review guided the formulation of six general research questions:

- (1) Does the type of strategy used during writing in terms of the sequence of planning activities affect quality of writing and learning? (Chapter 3)
- (2) Is there a cumulative benefit to be gained from engaging in multiple writing tasks? (Chapter 3, quantitative measure; Chapter 4, qualitative measure)
- (3) Will use of a modified laboratory report, the science writing heuristic (SWH), influence learning compared to writing in a more traditional format? (Chapter 4)

- (4) How does writing to audiences other than the teacher influence students' perceptions of learning (Chapter 3, to younger students) and does a different audience affect learning (Chapter 4, to peers)?
- (5) Are any performance differences related to students' sex? (Chapter 3 & 4)
- (6) What factors in the process of completing particular tasks do students identify as contributing to their learning? (Chapter 3 & 4)

#### Informed Participants

Prior to both investigations and in accordance with the university's Human Subjects Review requirements, the research project was explained to all students through reading and distribution of an informed consent letter. A sample from the second set of studies is enclosed (Appendix A). All students elected to participate in the studies. Students were informed that the objective of the research was to examine the influence of writing-to-learn strategies on student learning. However, to prevent threats to internal validity resulting from demoralization or rivalry of control group students, all students remained un-informed of the study's design, including their group assignment, throughout the study.

#### Dissertation Organization

From this initial introduction chapter, Chapter 2 in this dissertation consists of a review of the literature addressing both the theoretical issues and the implications from research that informed and framed the contents of subsequent chapters. Chapter 3 reports findings from an investigation designed to determine the influence of two different sequences of planning experiences on the quality of students' writing and learning. This chapter also explored the effects of two writing experiences compared to one writing experience. In Chapter 4, different types of laboratory writing experiences were used to support learning in

laboratory-based inquiry activities, and the influence from using traditional science report formats were compared to writing guided through a Science Writing Heuristic (SWH). In addition, the influence of the audience for a summary report was explored in comparing groups of students who wrote to the teacher to those who wrote to an audience of their peers. The main research questions are addressed in Chapter 5, which integrates a summary of the main findings and implications from Chapter 3 and 4, collectively.

Regarding the organization of Chapter 2, there is some complexity inherent in the processes of writing that might influence benefits from writing-to-learn strategies. Figure 1 illustrates the potential interaction of four main elements related to writing and students' conceptual understanding. In this figure, components of the learning environment include the resources available to the writer, such as a pen or computer, as well as the theoretical perspective of learning embraced by the teacher, which frames the environment of learning. The learning theory to which a teacher subscribes influences decision-making concerning task and topic choice as well as the writing-to-learn strategies employed to support understanding and engagement in such tasks. An interactive-constructivist perspective, for example, suggests such strategies include critical reading, inquiry, collaborative discourse and argumentation in combination with writing. From this perspective, engagement in these types of tasks might also be expected to influence success in writing as well as learning through the act of writing.

Perhaps any of the represented elements could conceivably support learning through writing. For example, a writing task may stimulate discussion, and likewise collaborative discourse could contribute to better learning and/or lead to better quality products through negotiated meaning making experiences. The potential a particular writing task has for

developing conceptual understanding may depend on the requirements of the task as well as the strategies implemented by the teacher. Conceptual understanding may be promoted through collaborative discussion, and likewise the current level of conceptual understanding influences the potential benefits to be gained from engaging in social negotiation, experiences which may also include writing. And so on.

The enclosed literature review attempts to explain the potential roles of components in these four elements that are important for consideration when attempting to support learning science through writing. Due to the connectedness of external influences (from environmental elements including social and pedagogical contexts) and internal factors within the learner, conceivably one could begin the discussion anywhere. The interconnectedness represented in the diagram should also illustrate that there was some difficulty not only in deciding where to begin, but also in attempting to construct a linear representation of the factors influencing writing, particularly because the processes involved in writing are clearly non-linear. While most of these points have been previously made and existed, "out there" prior to being expressed here, such as in the work of Flower and Hayes (1980, 1981, 1984), the difficulty was experienced first hand by the present author. Notwithstanding the challenge from limits inherent in textual presentation that complicated organization, contents of the major sections are foreshadowed next.

To provide context, "the end" in terms of where most educators want students to be is discussed in terms of conceptual understanding and learning is represented by a conceptual change model. Constructivism informed the pedagogical approaches in the present studies, framed the notion of a student-centered environment, and as such instruction included multiple strategies that engaged students in social negotiation through collaborative

discourse, argumentation, and hands-on inquiry investigations. Elements of writing models are presented as they provide the theoretical background specific to the factors involved in constructing writing, and explain how these factors interact to produce text. Research concerning writing in general, is presented as well as the research specific to writing utilized in science classrooms. The final section presents information concerning the benefits writing to learn strategies provide, and the implications from research as these findings suggest specific considerations important for the teacher. The last section ties the major implications from the literature to justify the present investigations. Definitions primarily relevant for the literature review are listed in Table 1.



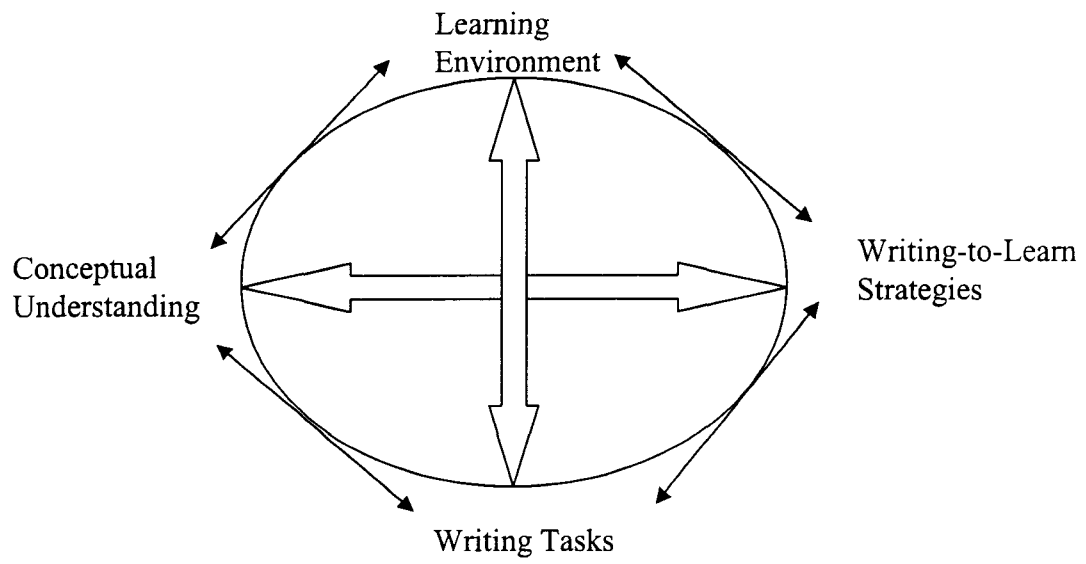


Figure 1. Interrelatedness of elements potentially influencing writing to learn.

Table 1. Definitions of terms pertaining to the theoretical framework in the literature review.

Term	Definition	Source(s)
ontology	"a theory of existence concerning the status of the world and what populates it" "the consideration of being: what is, what exists, what it means for something—or somebody—to be"	Ernest, 1996, p. 337 Packer & Goicoechea, 2000, p. 227
epistemology	"comprising (a) a theory of the nature, genesis, and warranting of subjective knowledge, including a theory of individual learning and (b) a theory of the nature, genesis, and warranting of knowledge (understood as conventional or shared human knowledge), as well as a theory of 'truth'" "the systematic consideration...of knowing: when knowledge is valid, what counts as truth"	Ernest, 1996, p. 337 Packer & Goicoechea, 2000, p. 227
methodology	"a theory of which methods and techniques are appropriate and valid to use to generate and justify knowledge, given the epistemology"	Ernest, 1996, p. 337
pedagogy	"a theory of teaching, the means to facilitate learning according to the epistemology" "the art or science of teaching; education; instructional methods"	Ernest, 1996, p. 337 Random House, 1998
modernism	"modern character, tendencies, or values; adherence to or sympathy with what is modern...a deliberate philosophical and practical estrangement or divergence from the past in the arts and literature occurring esp. in the course of the 20th century and taking form in any of various innovative movements and styles" -considering science as "the exemplification of rationality" -For Foucault, modernism attempts to control the dispersion and fragmentation of language that serves to dominate others	Random House, 1998, p. 1236 Marshall & Peters, 1999, p. 244

Table 1 (continued). Definitions of terms pertaining to the theoretical framework in the literature review.

postmodernism	"reaction to or rejection of the dogma, principles, or practices of established modernism" -Lyotard's interpretation conveys a skepticism of theoretical discussion about practices that serve to legitimize rules of knowledge in the sciences, justified, for example through references to universal principles; argues that commercialization of knowledge creates a gap between societies	Random House, 1998, p. 1511  Marshall & Peters, 1999
positivism	"a philosophical system founded by Auguste Comte, concerned with positive facts and phenomena, and excluding speculation upon ultimate causes or origins"	Random House, 1998, p. 1509
neo-	can imply any of the following: new, recent, revived, modified	Random House, 1998, p. 1287
absolute	"viewed independently; not comparative or relative; ultimate; intrinsic: absolute knowledge...(in Hegelianism) the world process operating in accordance with the absolute idea implies an unquestionable finality...something that is not dependent upon external conditions for existence or for its specific nature"	Random House, 1998, p. 7
realism	"interest in or concern for the actual or real, as distinguished from the abstract, speculative...the doctrine that universals have a real objective existence...the doctrine that objects of sense perception have an existence independent of the act of perception"	Random House, 1998, p. 1607
modified relativist ontology	"there is a world out there supporting the appearances we have shared access to, but we have no certain knowledge of it"	Ernest, 1996, p. 343
relativist epistemology	"there is no ultimate, true knowledge possible about the state of affairs in the world... [a pure form is] fallibilist, skeptical, and antiobjectivist"	Ernest, 1996, p. 341

Table 1 (continued). Definitions of terms pertaining to the theoretical framework in the literature review.

rationalism	epistemological position "holds that the main underpinning of human knowledge is the 'light of reason'"	Phillips, 1999, p. 249
empiricism	epistemological position that does not equate to realism, as some members may hold an "antirealist tendency...to lead to the view that the only realities are the empirically observable phenomena"; is antimetaphysical;	Phillips, 1999, p. 251
positivism	"one form of empiricism" with reasoning and evidence confined to the observable realm	Phillips, 1999, p. 252
logical positivism	another form of empiricism that is anti-realist, members can subscribe to operationism (a need to clarify concepts by revealing operational definitions, specifying procedures used in measuring) and be antimetaphysical by applying "verifiability criterion of meaning" through use of analytic or empirical procedure, meaning and verifiability still constrained by observation	Phillips, 1999, p. 254
non-foundationalism/ nonjustificationism	"[attributed to Popper among others] theories or hypotheses that have been adequately tested are tentatively accepted as knowledge – with the caveat that no knowledge is ever absolutely established"	Phillips, 1999, p.252
evaluativist	in the interactive constructivist position, science and knowledge are evaluated based on cannons from the modernist position	Yore, 1999
fallibilism	"belief that some or all claims to knowledge could be mistaken....Unlike a skeptic, the fallibilist may not demand suspension of the belief in the absence of certainty"	<a href="http://www.philosophypages.com/dy/f.htm">http://www.philosophypages.com/dy/f.htm</a>

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## CHAPTER 2. SUPPORTING SCIENCE LITERACY THROUGH WRITING-TO-LEARN: A LITERATURE REVIEW OF GOALS, WRITING MODELS, PROCESSES, AND STRATEGIES

A paper to be submitted to Review of Educational Research

Liesl M. Hohenshell

### Abstract

While the general problems identified over the past two decades appear to remain, a sustained effort has led to a body of research, which points to important connections between theory and practice when implementing writing to learn strategies to enhance science literacy. This review addresses different conceptions of scientific literacy and argues that a relative view focusing on developing critical thinking skills best matches goals from a variety of theoretical perspectives and modern philosophical views of science. Various constructivist theories of learning are explored and the pedagogical strategies reflected in the interactive-constructivist position are emphasized, as practices of inquiry, argumentation and writing are modes of learning particularly relevant to students' development of scientific literacy skills. The dominant models of writing are presented as they attempt to explain the cognitive processes involved in learning through writing. Suggestions from various research studies incorporating writing to learn strategies are presented, focusing on those implemented to support learning of science. One common implication across these various studies suggests that guided support, through scaffolded experiences, is necessary for students to experience success.

### Introduction

The purpose of this literature review is to provide a theoretical framework for interpretation of the studies included in this dissertation. I argue that writing-to-learn

strategies can be used as a medium to practice and improve science literacy skills, serving as a means for thinking and reflection, which promote students' efforts in transforming knowledge. While various conceptions of science literacy exist, the case is made for a relative interpretation that focuses on development of critical thinking and reasoning skills, which are readily adaptable and applicable to lifelong scientific learning. The current trend in the science literacy movement utilizes constructivist philosophy, embedded in student-centered environments, as the pedagogical guide to serve learning.

While several variants of this learning theory exist and are explored, the interactive-constructivist position informed the work enclosed, as this view best reflects how knowledge is constructed in the discipline of science. Both literacy and science educators who contend that meanings are socially negotiated and personally constructed embrace the interactive constructivist position and match the ontological and epistemological assumptions of current philosophical views of science. The pedagogical practices recommended from this perspective present science as inquiry and argumentation, which engage students in the activities and thinking practices similar to those of scientists, and in doing so support students' learning of scientific processes and content.

Writing serves as a tool for navigating learning in scientific practices, primarily by providing a medium for formulating understanding through expression. Negotiation and clarification of the language that has been represented stems from the permanence of the written product, which allows for sustained negotiation through reflection. Attention to rhetorical goals, such as writing to convey meaning to a particular audience, is a characteristic of expert writers and adopting similar goals and self-monitoring of progress toward these goals may promote students' learning of science concepts. Such learning occurs

through connecting ideas within the piece, and ordering the elements of the text to effectively communicate for an audience. Writing models describing these factors and the processes of writing are explained along with research that investigates how different writers attend to various factors because such characteristics may influence the ability to construct understanding through writing.

As a frame for the writing strategies implemented in the studies within this dissertation, recent, relevant research on writing-to-learn are discussed and results from preliminary research using the Science Writing Heuristic (SWH) are presented, highlighting the benefits implementation of particular writing activities provide learners as well as the implications for teaching and learning science that arise from these various studies.

### Conceptions of Science Literacy

Several definitions of science literacy have been put forth in the literature, and each of these is related to ideas concerning the nature of the concept as well as the arguments used to promote it as an educational agenda. This review describes various conceptions of science literacy and categorizes these in terms of two distinct views of the topic. I also address the reasons for advocating this focus in education and present characteristics of scientifically literate persons as described in national and international documents outlining science literacy goals, as these are immediately relevant for classroom teachers. Additionally, a few proposed ways of measuring skills and attitudes related to science literacy are also introduced. The argument embedded throughout this section supports an interpretation that focuses on development of critical thinking skills and communication of understandings relevant to science and learning throughout a lifetime (Hand, Prain, Lawrence, & Yore, 1999).

In attempting to describe scientific literacy, several authors have outlined different levels or degrees of literacy often based on categorization of a segment of the population. In his review, Laugksch (2000) classified various conceptions of science literacy and linked each of these to a view of science literacy as either absolute or relative. Of these two features, absolute association was made when interpretations relied on discipline-defined, existing concept knowledge, while the other feature focused on interpretation within a social context, that is conceptions are socially defined, relative to society, allow for modification of ideas, and are dynamic in the sense that they may differ in time and between or among communities.

Some science literacy documents contain both absolute and relative features in elements composing different levels of literacy. For example, Shen (1975) described three main types of science literacy: practical, civic, and cultural. For the average person, practical literacy includes knowledge of science important for survival, relating to issues of health and shelter for those in developing nations and “consumer protection efforts” for those in industrialized countries (as cited in Laugksch, 2000, p. 77; Shamos, 1995). Civic literacy enables the average citizen to effectively contribute to the democratic process, by using knowledge from science to make informed decisions such as on issues concerning the environment. Shen also considered cultural literacy had the potential to inform public policy so there is some degree of overlap; however, this stage for him, is primarily reserved for intellectuals in the academic community concerned with knowing more about the discipline and its achievements, and was therefore considered as an absolute view (Laugksch, 2000). On the other hand, Laugksch (2000) suggested the first two types of literacy, practical and civic, imply a view of scientific literacy that is contextual and relative to society because a



change in ideas is recognized and required knowledge may differ in time, as well as between and among communities.

While at least two additional authors (Hirsch, 1987; Shamos, 1985) have used the term cultural literacy with slightly different interpretations, Laugksch identified the common thread across these authors was in their absolute perception of science literacy. This is important because the term, cultural literacy, may imply a more broad interpretation within a cultural context; however, use of this term in actuality does not. All descriptions of cultural literacy rely on existing conceptual knowledge in the field of science. Since Hirsch's (1987) publication, the term "cultural literacy" has become linked to the idea that literate individuals possess a mastery of science content according to a list of scientific terms and concepts. Shamos (1985) attributes the description of his first and "simplest" level of literacy to this list put forth by Hirsch and retains the language for his initial level "Cultural Scientific Literacy" (p. 87), which applies to adults who recognize basic science terms. Others, such as Hazen and Trefil (1991) also focus on specific knowledge of science content and likewise have been classified with an absolute conception of literacy (Laugksch, 2000). Interestingly, as Paisley (1998) points out, Trefil contributed to the construction of Hirsch's 1987 list.

Cultural literacy is typically associated with mastery of material with competence reflected in extensive use of the language (Shen, 1975; Shamos, 1995). It is unlikely that most adults could provide written definitions from memory for all the terms in Hirsch's 1987 list. Today, a more general list of content is recommended for teachers and students in the National Science Education Standards for the United States (NRC, 1996). These recommendations place greater emphasis on conceptual understanding, among other skills and attitudes that are characteristic of literate persons. More details of such characteristics

are further explained in a subsequent section of this dissertation; however, a few critics of this particular list deserve attention here. In the document, DeBoer claims "the definition of scientific literacy is broad and includes virtually all of the objectives of science education that have been identified over the years" (2000, p. 590). He points out that even though there is some freedom afforded in the national standards, in that implementation is the responsibility of teachers, "they also say that scientific literacy is defined by the content standards and that none of the standards should be omitted" (2000, p. 595). He suggests abandoning pre-determined content sets because "we do not have to master all areas of knowledge to live successfully in our society, and awareness of this fact may free us to explore more creatively how to deal with questions of scientific literacy" (2000, p. 595). Similarly other critics argue that the overarching goal of reform efforts have remained essentially static, directed "to produce more people with better knowledge of key concepts and prepared to act like 'real' scientists...reform proposals offer slightly different approaches to pursuing this endpoint, they do not challenge the endpoint itself" (Eisenhart, Finkel, & Marion, 1996, p. 268). These authors do challenge the endpoint, framing it as an assumption. They argue that teaching key concepts and inquiry, and learning to act like scientists will not necessarily result in acting in socially responsible ways. Ennis reminds readers that while sensitivity "to the feelings, levels of knowledge, and degree of sophistication of others" (1985, p. 54) is included as a dispositional component of critical thinkers, it is more appropriately considered "a social disposition that is desirable for a critical thinker to have (p. 57).

Moving from the initial "cultural" level, Shamos proposed two additional levels of scientific literacy; although, all of these were linked to an absolute view by Laugksch (2000).

The second level of science literacy Shamos proposed, called “Functional Scientific Literacy,” increases the degree of sophistication in applying science concepts. At this level, a person is able “to converse, read, and write coherently, using such science terms in perhaps a non-technical but nevertheless meaningful context” (1995, p.88). His third and highest level places focus on the nature of science, and is called “‘True’ Scientific Literacy” (1995, p. 89). This occurs when an individual demonstrates understanding of the process of science, the role of theory, and the elements of experimentation, including reasoning and objective evidence. Shamos considers this level difficult to obtain and measure; he estimates it is present in less than ten percent of the population. This is one reason his recommendations differ for students not on a career science track. With little focus on critical thinking and increasing emphasis on technology, his “three guiding principles” for teaching these students are: 1) “as a *cultural* imperative,” moving from a focus on content to “appreciation and awareness” of the discipline; 2) “as a *practical* imperative,” in which instruction is centered on technology; and 3) to promote “social (civic) literacy” through “the *proper* use of scientific experts” (1995, p. 217). Shamos developed his own list for the general science student (and early education of the career track student), although succinct and less prescriptive compared to the list proposed by Hirsh nearly a decade earlier (for the complete list see Shamos, 1995, p. 223-224). Nonetheless, Shamos' proposal has been labeled “radical” due to the emphasis on technology and “in the way it removes responsibility for decision-making regarding science-based issues from the general public in favor of science experts” (DeBoer, 2000, p. 591). Others have rejected an emphasis on understanding the principals behind technological tools because one can operate devices such as a computer

"with almost no understanding of how they work" (Millar & Osborne, 1998, p. 2011).

Instead, these authors accentuate thinking with pragmatic appeal:

On a practical level, an understanding of scientific ideas can help people in decision-making (for example, about diet, health, and lifestyle more generally), and in feeling empowered to hold and express a view on issues which enter the arena of public debate and, perhaps, to become actively involved in some of these" (Millar & Osborne, 1998, p. 2007).

While Shamos considered critical thinking more important for the teacher than the general student, others see critical thinking as a central curricular focus (Ennis, 1985). Ennis (1985) used this general definition, "critical thinking is reasonable, reflective thinking that is focused on deciding what to believe or do" (p. 54); although in the subsequent description of dispositions and abilities characteristic of critical thinkers, he essentially constructed his own complex list. Some might consider the detailed outline of 12 abilities he provided challenging for even those pursuing graduate degrees to fully demonstrate. This particular list however, does offer an opportunity for teachers to reflect on the kinds of thinking their instruction stimulates students to do. Similarly, DeBoer (2000) points toward the comparative value of goals in standards documents for teachers' thinking about their own ideas and reflecting on their lessons.

In his more recent review of science literacy, DeBoer (2000) criticized the lists and the all-encompassing descriptions of literates and instead argued for maintaining a broad conceptualization that allowed local interpretation of meaning and a more community-directed approach to implementation. While Laugksch (2000) had not categorized conceptions in this article, DeBoer's case fits under a relative conception. DeBoer threaded the notion of preparation for democratic participation in several goals of science teaching. In the end, he argued,

Ultimately what we want is a public that finds science interesting and important, who can apply science to their own lives, and who can take part in the conversations regarding science that take place in society. Not everyone will develop the same knowledge and skill, but feeling that one can continue to learn and participate are key elements to life in a democratic society (DeBoer, 2000, p. 598).

It appears that if the main argument for promoting science literacy is based on developing an educated and competent citizenry for participation in a democracy, then critical thinking, as a goal, should be at the forefront of these efforts. Rather than focus on a stored bank, set of details, or specific knowledge base, the populace would be better served by developing attitudes, skills, and characteristics supportive of a lifetime of learning. These characteristics include openness to alternative ideas, willingness to modify existing conceptions, and the ability to analyze evidence in light of a particular view, determining whether it is confirming, disconfirming, or inconclusive.

The ability to communicate these ideas and characteristics to others is an essential component because 1) the act of communicating thoughts allows ideas to be revealed and sometimes realized in the first place, 2) thoughts and views may change through social negotiation, and 3) ideas can only be assessed by others after they are made public.

Ultimately, communication is what empowers individuals to be heard; it is required for contributions to discussions and change cannot occur without it. It seems as though all conceptions of literacy, regardless of the purpose or target, would be strengthened by an emphasis on critical thinking and communication. However, not all arguments incorporate these elements as central goals. When these elements are emphasized in an argument, the conception is based on a relative view of science literacy and the impetus tends to highlight the individual's role as a participant in a democracy.

### Reasons for Advocating Scientific Literacy

Reasons used for an impetus of scientific literacy fall into several categories, and as with various interpretations, each argument has some degree of overlap. Each reason has an individual component or at least an implication for the individual. Reasons often direct the focus or outcome of instruction, answering the question, "who is science education for?" In addressing this question, reasons for advocating science literacy tend to emerge from a utilitarian perspective, ranging from benefits gained by the scientific enterprise itself to preparing individuals for democratic participation in society.

Media reports emphasizing public ignorance have been used to argue for the development of science literacy as a means to recruit and retain funding support for science programs (Paisley, 1998). Justification for this argument has been extended based on concerns for national security (DeBoer, 2000) and gained momentum after Sputnik in 1957 (Shamos, 1995). This theme of inadequate funding is renewed in initial citations of "cause" during times of crisis and disaster, such as when the space shuttle Columbia failed to safely return to earth on February 1, 2003. In addition, Shamos claimed that one enduring purpose of science education has been for adequate preparation of a work force for science-related fields, and this purpose persists internationally (Galbraith et al., 1997). Differential training of youth over the age of sixteen interested in these various disciplines (to help accommodate pursuits for this subpopulation) is also part of current recommendations in national documents of England and Wales (Millar & Osborne, 1998). Contesting such a focus on instruction to train scientists (as have others, e.g. Paisley, 1998; DeBoer, 2000), Galbraith et al. explained one problem with this direction:

it has been traditional for science to be taught as if all its students might become scientists, while at the same time providing a type of delivery which clearly puts it beyond the comprehension and certainly the interest of a majority of its recipients (1997, p. 462).

These authors argue against the "economic rationalist approach" for production of a work force, in favor, rather of science literacy that "will be determined more by the needs of independent citizenship" (p. 447 & 463). Shamos argued that there is too much content for any single person to master for "personal expertise" (1995, p. 77). According to Thistle's estimation in 1958, "only one hundredth of one percent of all current science information could be communicated to the public" (Paisley, 1998, p. 71). Considering that information and ideas accumulate, the amount of material is simply too much to introduce or master.

In a related argument against a selected target of instruction, it is not only the amount of material, but also the level of difficulty that influences learning science content. Some of the characteristics of science that make mastery and retention of knowledge difficult include the centrality of mathematics and the cumulative and transitory nature of knowledge in the discipline (Norman, 1998; Paisley, 1998; Shamos, 1995). These authors recognize the myriad of scientific detail, which dictates that experts in physics are not likely to know all the principles of biology (and vice versa). They also recognize that science literacy in adults is influenced by knowledge retention; and to maintain mastery of a topic, action is required either to refresh memory or modify and revise existing conceptions when new developments arise. This is one reason behind why motivation for students to become and remain literate in science must come from a realization of personal benefits gained from an active pursuit of knowledge and interest in the scientific discipline as argued by several authors (Shamos, 1995; DeBoer, 2000; Millar & Osborne, 1998; Hand, Prain, Lawrence & Yore 1999). This

line of reasoning is present in documents expressing "a need for individuals who have a broad general education, good communication skills, adaptability and a commitment to lifelong learning" (Millar & Osborne, 1998, p. 2001). Careful not to overemphasize personal use for "action," Millar & Osborne (1998) argue that students should feel prepared with confidence and basic background to facilitate pursuit of their interests, such as current science topics for debate and democratic participation or other science related issues that may be of potential use in the future. For DeBoer (2000), "the important thing is that students learn something that they will find interesting so that they will continue to study science both formally and informally in the future" (p. 597).

Considering the arguments made against prescriptive lists toward a more self-directed utilitarian view, there seems to be a need for a more dynamic interpretation of science literacy, one that is more reflective of the additive and relative nature of the discipline (Laugksch, 2000; Paisley, 1998). Several authors (Shamos, 1995; Paisley, 1998; Eisenhart, Finkel, Marion, 1996) call for another approach, situational (or problem-oriented) literacy, with flexibility to develop the concept as needs arise. While Shamos might be criticized for centering his notion of relevant problems on technological issues, his emphasis on using problems that have meaning for students is essential. The problem-oriented approach makes sense in preparation for an unpredictable future. In surveys of experts from a variety of disciplines commenting on science literacy, Galbraith et al. (1997) found that "what is *expected* to emerge as basic knowledge in the future falls considerably short of what is *desired* for that time" (p. 163). There is no way to account for all the issues that may be of concern or topics of public debate. Given that the ability to predict all of the potentially relevant issues and sufficient coverage of content are not possible (Galbraith, et al., 1997),



and because time will pass between initial exposure and application requiring refreshment as adults (Paisley, 1998; Shamos, 1995), it would be better to prepare students with certain abilities necessary for self-directed pursuits (Hand, Prain, Lawrence & Yore, 1999). Skills would include self-confidence and the habits of mind necessary to independently research background information. These sentiments are also reflective of DeBoer's (2000) contention. Additionally, there should be a focus on including issues relevant to the local community. The work of independent research includes compiling and integrating information to develop a logical argument in support of a claim; and these activities are fundamental abilities for such literacy (Millar & Osborne, 1998). Thus, a relative and dynamic interpretation of literacy for future application and use of information houses critical thinking at its core.

Unlike Shamos, others recognize the centrality of thinking for students. Von Glasersfeld (1993) argues that in teaching and learning "successful thinking is more important than 'correct' answers" (p. 33). Critical thinking is particularly important when the impetus is for democratic participation (Hand, Prain, Lawrence & Yore, 1999; Hurd, 1998; Kyle, Linn, Bitner, Mitchener, & Perry, 1991; Yore, 2001). Whether it be making informed decisions from science topics in the news (Hallowell & Holland, 1998; DeBoer, 2000; Millar & Osborne, 1998), or "a continued willingness to apply scientific habits of mind in a wide range of social contexts" (Hand, Prain, Lawrence & Yore, 1999, p. 1021), integration and synthesis of ideas are essential abilities that require, at some level, reasoning.

Integration is the basic tenant in yet another case for scientific literacy, one that focuses on the social implications of science and technology (Bauer, 1994). Supporters of this view advocate the use of Science, Technology and Society (STS) programs to present information in a manner that is immediately relevant and practical. For example, scientific

concepts might be presented and explored through thematic units centered on a topic that is locally relevant to the community, such as investigating water quality in a local stream or pond. By necessity, this case entails how an individual uses scientific information. For example, Shamos and those who emphasize the nature of science, contend that individuals who understand the process of science will be able to discriminate "pseudoscience" from real science. In this way, Shamos agrees with Conant in engendering "the ability to choose one's experts wisely," (Shamos, 1995, p. 86) as opposed to trying to make each person an expert. Initiative to seek advice, communication with scientific experts, analysis of conflicting arguments and evidence, and discrimination of the term "expert" are only some important characteristics necessary for individuals to achieve this goal. Even when critical thinking is not recognized at the core, the goal for students to become critical consumers of information and analyzers of "credible experts" (Shamos, 1995, p. 77) also requires, at some level, developed reasoning.

The final reason for advocating scientific literacy addressed in this review extends those previously mentioned. It combines the societal impact of science with critical thinking, offering a focused purpose for empowerment of the individual. In arguing for a reinterpretation Hanrahan (1999) suggested that science literacy should have:

less to do with producing correct technical terms and a particular kind of rationality, and more to do with teachers and students engaging each other in ways which are personally meaningful and which promote not only better communication in the short term, but also better personal understanding of the interaction between humans and their environment in the long term. (p. 714)

Similarly, Norman (1998) argues for viewing "science as a human enterprise" (p. 371).

Through study of past scientific agendas in literature and discourses outside of science, Norman contends that by critiquing elements of sexism, racism, and classism inherent in, but

not exclusive to, the discipline of science, students will be positioned to analyze present circumstance and make judgments concerning what is unacceptable. From the opportunity to analyze and critique, students may be better situated to prevent or avoid future exploitation. For Norman, the major goal of science literacy is empowerment so that students “critically evaluate the ideological implications of individual scientific claims and practices” (1998, p. 365). Critical theory is also present in literature concerning literacy in general. Giroux and McLaren (1992) argue that “literacies are not just about language but also refer to the effects that cultural politics and social relations of power have upon the act of interpretation and the generation of meaning” (p. 27). In addressing Laugksch’s suggestion that researchers “spell out their position(s) with respect to relevant factors of scientific literacy when discussing this concept” (2000, p. 90), it is this final view that frames scientific literacy for the purpose of the work in this dissertation. Specifically, teachers should support students in their individual pursuits of scientific literacy through development of critical thinking about science content and the scientific enterprise, with the ultimate goal of empowering these individuals with skills and understandings related to the discipline. The abilities involved in communicating these understandings to inform and compel others to take action are also important components of scientific literacy (Hand, Prain, Lawrence, & Yore, 1999; Yore, 2001; Yore 2000). Such skills and understandings can then be taken and applied to life beyond the classroom in whatever way and for whatever purpose the individual needs or chooses. To see an implication of an idea or discipline, one must first comprehend, or at least have a sense of that idea or discipline. Such augmentation is best served through critical thinking practice. This view is consistent with, albeit an extension of, von Glasersfeld's two goals of education, “first, to foster thinking that does not involve

conceptual contradictions and that leads to internally consistent results. Second, to introduce students to the consensual domain that governs the discipline at the moment" (1993, p. 35).

An approach with emphasis on critical thinking should appeal to opposing philosophers representing extremes sides of the camp. Among positivists, for those committed to realism and believing in truth, if there is one correct way concerning any topic in science, then sound reasoning will eventually lead there. For those who do not subscribe to the existence of an absolute truth, postmodernists, for example, may be equally appealed as engaging in critical thinking, by nature, requires one to be open to alternative ideas for review and may also encourage the learner to recognize flaws, resulting in improving a personal argument or facing a need to change. While postmodernists such as Lyotard are skeptical toward theoretical justification about practices that serve to legitimize rules of knowledge in the sciences, through reference to universal principles among other means (Marshall & Peters, 1999), it is through critical thinking that such incredulity and critique has been formulated and can be recognized. Furthermore, to protect someone from a "commercialization of knowledge" (Marshall & Peters, 1999, p. 243) that amplifies societal gaps, is first to empower individuals in society with the canons, claims, warrants, arguments, and practices associated with such knowledge. Again, the means and end are best served through a main goal of critical thinking. For pragmatists, the element of critical thinking lends itself to practical application and is present in current national goals and standards' characterizations of literate persons. Additional characterizations and recommendations are discussed in the next section because these are immediately relevant to classroom teachers and students.

### Goals for the Scientifically Literate

While there is general agreement that students should possess awareness about the nature of science, inquiry, literacy, reasoning, and epistemology, there is still controversy regarding meaning(s), the method(s) of integration of these abilities and concepts, as well as the extent to which each should be emphasized during instruction (Hand, Prain, Lawrence & Yore, 1999; Norman, 1998; Shamos, 1995). A universally accepted method of measurement of what constitutes science literacy is also absent (Laugksch, 2000). However, these limitations have not prevented descriptions of the qualities held by a scientifically literate person, and these are often discussed as "goals" in the literature.

The main views of scientific literacy previously discussed are reflective of three related criteria for the literate as one who has, enough basic science vocabulary to read media reports, an understanding of the science inquiry process, and an understanding of the impact of science and technology on society (Miller, 1983; Miller, 1998; Shamos, 1995). One persistent goal in western literacy instruction in general has been "teaching students to read to comprehend and teaching students to write to convey their thoughts in print" (Dixon-Krauss, 1996, p. 8), although instructional strategies to achieve the goal have varied markedly over time. The "literate" portion of scientific literacy implies that one can not only read literature about science, but also communicate understanding, both verbally and in writing. Understanding, Shamos claims "parallels the early constructivist concept of knowing as being able to explain it satisfactorily to others" including experts and novices, and can be demonstrated by teaching information through explanation "with the ability to extrapolate to other related examples" (1995, p. 100). For an interesting historical citation see Yager (1991), who traced this notion through Ernst von Glasersfeld to a Neapolitan

philosopher, Giambattista Vico, who asserted "one knows a thing only when one can explain it" (p. 54; also in Ernest, 1996). Others (Holliday, Yore, & Alvermann, 1994) currently espouse this communicative theme, "the 'fabric of scientific knowledge' must be preserved through scientific knowledge, methods and principles which, together with the ability to communicate, are deemed essential for scientific literacy in the years ahead" (Galbraith, Carss, Grice, Endean, & Warry, 1997, p. 463). In describing constructivism for teachers, Yager (1991) asserted that, "all learning is dependent upon language and communication" (p. 53). Sutman (1996) emphasized the compatibility of a communicative focus with constructivist theory. According to him, recognizing that different levels of attainment of science literacy will vary within and between individuals over time is important; and allowing for this variety in conceptualizing science literacy is more in line with constructivist thought. Arguing for a definition of science literacy that is independent of mastering a particular content set or amount of material Sutman (1996) proposed, "an individual is science literate when that person is able and willing to continue to learn science content, to develop science processes on his or her own, and able to communicate the results of this learning to others" (p. 459-460). What is being communicated is important to address as several authors point to the central role of language in literacy.

In analyzing surveys from "expert" respondents representative of science and education community members contributing their perceptions of science literacy, Galbraith et al. (1997) found "no relaxation in demands for the proper use of scientific language and conventions" (p. 459). One respondent quoted stressed the point that the "'language of science must remain critical and tight—but as a tool for science, not an end in itself'" (p. 459). However, Giroux and McLaren (1992) argue for application of both critical pedagogy

and critical literacy to examine the social realm and cultural contexts in which language is used and how various contexts influence the purpose(s) behind language use because "it is largely through language that meaning is created...language produces *particular* understandings of the world [emphasis theirs]" (p. 12). For an explanation particular to reading text, "words have meaning for the authors and the readers...[because each] has built up her subjective meanings according to her individual experience" (von Glasersfeld, 1993, p. 30). Giroux and McLaren (1992) point out "the importance of language resides in the fact that it is through language that we both *name* experience and *act* as a result of how we interpret that experience," which is relevant for educational researchers as well as "students who are attempting to critically analyze their everyday experience" (p. 15). Emphasizing the role of "language development beyond memorization of the science vocabulary" in his conception, Sutman criticizes the lack of attention on the fundamental element of language, "the fact that science literacy cannot occur outside of overall language literacy is seldom discussed by science educators" (1996, p. 460). Yet, language use and effective communication are threaded throughout the "scope and sequence" descriptions in National Science Education Standards as content is organized "with increasing precision and more scientific nomenclature" as grade levels progress (NRC, 1996, p. 111).

Recent attention has addressed the language "literacy" component of science literacy. Norris and Phillips (2003) referred to reading and writing about science content as the "fundamental sense," and being knowledgeable about science as the "derived sense" of scientific literacy. These authors argue that science literacy theorists have largely ignored the fundamental portion, which in western science is basic to the nature of the discipline, working within it, and learning about it. Six main points were at the crux of their argument

as to why western science would not exist as it does today without reading and writing, the fundamental sense, and why this part is essential to learning science. In summary, they argued:

coping with speech and coping with text are not the same; that supremacy lies with neither the text nor the reader; that text is an essential vehicle for the expression of scientific thought; that, although fixed, texts permit interpretation and reinterpretation; that the very words matter as constraints to interpretation; and that scientific knowledge relies upon the cumulative discourse made possible by text (Norris & Phillips, 2003, p. 233).

Expanding on two main differences between verbal and textual expression that influence interpretation these authors explained, 1) there are certain cues conveyed during talk, such as gestures, tone, incomplete thoughts, and stammers that necessarily lack in text, and 2) also by nature of text, there are additions not present in talk, such as style and format, and in the structuring of sentences and paragraphs a close, logical progression can be represented (see Olson, 1994 as well). Emig (1977) also distinguished talking from writing, which lacks presence of a physical audience and thus writing has to supply the context. In being a visible representation of the world in a permanent product, writing is generally "a more responsible and committed act and...more readily a form and source of learning than talking" (Emig, 1977, p. 124). Greene and Ackerman (1995) argued "that reading and writing are inseparable from each other and from other modes of meaning making" (p. 383). With the previous arguments in mind, there is a need for students to take part in critical reading of science materials to identify claims and evidence, and there is also a need for students to practice constructing text as a means to make and demonstrate understanding of connections. For Giroux and McLaren (1992) critical reading is not



a process of submission to the authority of the text but as a dialectical process of understanding, criticizing, and transforming. They [students] need to write and rewrite the stories in the texts they read so as to be able to more readily identify and challenge, if necessary, how such texts actively work to construct their own histories and voices (p. 19).

In addition to the abilities to read and write about science, descriptions of literates often include an outline of general procedural and declarative knowledge students should possess. Rutherford and Ahlgren characterized the scientifically literate individual as one who is aware of the strengths, weaknesses and interdependence of mathematics, technology, and science; recognizes these as human endeavors, "understands key concepts and principles of science; is familiar with the natural world and recognizes both its diversity and unity; and uses scientific knowledge and scientific ways of thinking for individual and social purposes" (1990, p. ix).

Similarly, the National Science Education Standards also accentuate knowledge and understanding of science and technology as it applies to the natural world, so individuals can use information personally and as effective participants in an economically productive society (NRC, 1996). The declarative knowledge described in the document is embedded in a series of content standards, which include the use of technical terms, scientific facts, concepts, processes, principles, laws, theories, and models. Understanding that integral relationships between scientific terms, facts, and concepts exist, how and why they are related is also considered important. Some of the procedural knowledge specified includes the ability to ask questions, describe, explain, and predict natural phenomena. Additionally, the scientifically literate person should be able to construct and evaluate arguments based on evidence and to formulate conclusions. An inquiry approach to science is emphasized, in which students practice methods similar to those scientists use and through these actions are

“proposing explanations based on evidence and logic rather than on their prior beliefs about the natural world” (NRC, 1996; p. 173). And thus in doing they will come to a better understanding of how these activities relate to science. There is a trend away from viewing the scientific method as a single, rigid, step-by-step, procedure of experimentation. The current view moves toward a focus on students' ability to think critically about multiple scientific processes and make inferences about results obtained from actively engaging in investigations (Hand, Prain, Lawrence, & Yore, 1999; NRC, 1996; Rutherford & Ahlgren, 1990).

These goals are not confined to the United States. Authors from England and Wales identified a need for students to appreciate how inquiry is conducted "to help them appreciate the reasoning which underpins scientific knowledge claims, so that they are better able to appreciate both the strengths and the limitations of such claims," (Millar & Osborne, 1998, p. 2011-2012). The "scientific approach to inquiry" is important, which is "based on evidence and careful reasoning, with all claims open to critical scrutiny by a community of inquirers" (Millar & Osborne, 1998, p. 2007). The processes involved in looking at communication within the discipline of science is also important for learning, "by considering the ways in which evidence and argument have been employed to establish reliable knowledge about the natural world...young people acquire and develop important skills and understandings" which can be used later in life (Millar & Osborne, 1998, p. 2008). Elements of inquiry and scientific argument are also expressed by others who see engagement in the methods as helping students understand some of the aspects in the nature of the discipline:

Learning science involves young people entering into a different way of thinking about and explaining the natural world; becoming socialized to a greater or lesser

extent into the practices of the scientific community with its particular purposes, ways of seeing, and ways of supporting its knowledge claims (Driver et al., 1994, p. 8).

Constructivists regard learning science concepts as an interconnection of inquiry experiences and representation of argumentation elements. Tobin and Tippins (1993) argue that

Making sense of science is a dialectical process involving both content and process. The two can never be meaningfully separated. The process skills can be thought of as thinking processes, such as using the senses to experience; representing knowledge through language, diagrams, mathematics, and other symbolic modes; clarification; elaboration; comparison; justification; generation of alternatives; and selection of viable solutions to problems. (p. 9)

In addition to the increased emphasis on critical thinking and inquiry, there is also more focus on communication and learning in constructivist environments in national documents for science (Hand, Prain, Lawrence & Yore, 1999) and mathematics education (Richardson, 1997). Teaching for understanding is emphasized in various national documents and reform initiatives through student-centered teaching practices, which are also commensurate with constructivism (Windschitl, 2002). Such practices include, using students' interests as one guide for instructional activities, facilitating meaning-making discussions between students, and providing assessment opportunities for which students provide evidence of understanding (Windschitl, 2002). Inquiry, communication, and constructivism are common yet fairly complex themes, and are thus expanded on in later sections.

The goals from the NRC are immediately relevant to classroom teachers. As Lederman and Flick declare (2004) the goals and outcomes of school districts are a "reality whether we like it or not" (p. 54). Science content standards are relevant because they serve as a guide for reform issues, curriculum development, textbook content in new editions, assessments, and are likely to be the basis for future accountability measures of performance for both teachers and students. Teachers struggle to translate ideas from literature and

district mandates into practical applications for their students (Windschitl, 2002), that is, pragmatic application is of immediate interest to most teachers. All concerned share common assumptions. The movement toward a more competent, scientifically literate public necessitates enhancing understanding of science content *and* this can be mediated through efforts at the classroom level.

The main argument in this section was that when education is designed to support students in developing attitudes and abilities for participation reflective of democratic ideals, it necessarily embodies critical thinking at its core and is consistent with a relative interpretation of science literacy. Pragmatic pursuit of such broad literacy goals may be guided by content in national standards documents and district standards, benchmarks, and proficiencies. While documents that are more prescriptive might be considered constraining, the local, community products do provide immediately relevant focus topics for instructional practice. Under a relative interpretation of literacy, all content guides are open to development and future revision. Understanding of content is reflected in language use and as such, communication not only provides evidence of understanding, but also fosters development of science understanding. In the next section, the theoretical framework for the studies enclosed is presented. Constructivism serves as the foundation for classroom environments that support critical thinking and content understanding mediated by strategies that promote negotiation of meaning through communication, specifically, inquiry, collaborative discourse, scientific argumentation, and writing-to-learn activities.

#### Theoretical Framework

The classroom environment promoted in national standard documents and reflected in most of the writing-to-learn research in this review is informed by constructivism, but the

term to this point has been only vaguely alluded to. Constructivism espoused in the documents is "generally defined as a collection of theoretical approaches sharing the idea that knowledge, beliefs, values, and meaningful behaviors are constructed in experience" (Eisenhart, Finkel, Marion, 1996, p. 275). The term has been used as a theory, model, pedagogy, method, tool, referent, philosophy, epistemology, postepistemology as well as a paradigm or metaphor in literacy and science education research. Ernest (1996) uses some of these various representations to declare constructivism is the prevailing research paradigm (as have others, Brooks & Brooks, 1993). Ernest discusses three major forms of the paradigm, weak constructivism, radical constructivism, and social constructivism and reveals distinctions between them in terms of ontological and epistemological commitments. Multiple interpretations of the term impart suppleness as well as a base from which teachers can draw to stimulate their own ideas for classroom practice. The purpose of this section is to explore each of these forms along with a fourth perspective, interactive-constructivism. Rather than conceptualizing the forms as situated along a continuum, I suggest that interactive-constructivism, as a synthesis, adds a third dimensional view. Informed by the interactive-constructivist perspective, this section clarifies the theoretical framework, for learning, teaching and research design of the papers in this dissertation.

Current conceptions of constructivism have largely been shaped by Piaget, von Glasersfeld, and Vygotsky; almost with certainty, at least one of these authors will be found discussed in the literature on this topic, although Vygotsky is most often discussed in social constructivist literature. Early reference to the term is attributed to Piaget (1937) because he emphasized the child's role in construction of knowledge (von Glasersfeld, 1996a). Piaget considered knowledge construction to be a personal process involving an important element

of self-regulation (Driver & Oldham, 1986) or what he called "equilibration" (Piaget, 1964, S10). According to von Glasersfeld (1996a), construction was not intended to describe knowledge as merely additive, although early interpretations erroneously attended to this point. Those who still embrace this simplistic approach have been labeled "trivial" constructivists (von Glasersfeld, 1996a; Tobin & Tippins, 1993, p. 6). It is important to note also that early conceptions did recognize social interactions for their "powerful influence," but the focus was primarily on the individual constructing knowledge (von Glasersfeld, 1993, p. 24, Ernest, 1996).

The essence of a constructivist position has to do with conceptions of the nature of knowledge itself, which is considered "actively built up" by individual learners as opposed to being dispensed from one person to another (Driver, Asoko, Leach, Mortimer, & Scott, 1994, p. 5; von Glasersfeld, 1993, p. 26). "Cognitive" (Windschitl, 2002, p. 140), "Piagetian" (Eisenhart, Finkel, Marion, 1996, p. 276), or "weak" constructivism (Ernest, 1996, p. 339) is the form that is seen adhering to only this first principle of von Glasersfeld (1989, p. 182), that is, all knowledge is "actively built up" by individuals and "not passively received". Individuals construct knowledge; but that knowledge may still be considered in "a realm of objective knowledge, "which include "truths" and external "facts about the world" (Ernest, 1996, p. 339). The weakness according to Ernest, stems from an epistemological conflict, "that is, it accepts traditional epistemology concerning knowledge, and only tries to account for the knowledge representations of individuals" (1996, p. 340). To help distinguish this form from radical and social constructivism, see Table 1, which represents a synthesis of classifications according to various authors (modified from Ernest, 1996; Eisenhart, Finkel, & Marion, 1996; Yore, 2001). It should be noted that individual interpretations and

applications of these various forms of constructivism may not fit "neatly" into these categories, but this organization was chosen to facilitate presentation of essential features and as Ernest claims, does offer an opportunity to expand the discussion of paradigms (Ernest, 1996, p. 347).

In Table 1, radical constructivism is presented as ontologically "neutral" (Ernest, 1996, p. 341). This form is best explained by one of the more commonly cited radical constructivists. For von Glasersfeld (1993), constructivism is "one possible way of thinking. It is a model, and models, no matter how useful they may prove, must never be claimed to be 'true'" (p. 23). Constructivism is primarily an "exercise in epistemology," addressing the questions of knowledge, what it is "and where it comes from" (p. 23-24). Conceding to the "postepistemological" label put forth on his conception by Noddings (1990), von Glasersfeld interprets constructivism as "a theory of knowing" because in his view, "the only world we can know is the world of our experience" (p. 24). Inherent in his view is an essential element of subjectivity from which there is "no exit...[because the] experiential world is constituted and structured by the knower's own ways and means of perceiving and conceiving, and in this elementary sense it is always and irrevocably subjective" (von Glasersfeld, 1996a, p. 308). Although the reality of an outside world is not denied, "the 'real' world remains unknowable no matter how well we manage in the domain of our experience" (von Glasersfeld, 1993, p. 25; Tobin & Tippins, 1993). For the learner, some conceptions work, others do not, and just because some conceptions appear "viable" does not mean that others are not or will not become viable. Truth in his sense of constructivism is replaced with "viability" (von Glasersfeld, 1993, p. 25). It is through this criterion of viability that von Glasersfeld defends his position, which he contends is "as consistent as possible" and

"seems to be the most plausible view at the moment" (1993, p. 29). Importantly, viability is also the major criterion he recommends for teachers when assessing students' thinking about topics. This form, according to Ernest, represents an educational paradigm because all dimensions, ontology, epistemology, pedagogy, and methodology have been "fully developed....[and] extensively treated in the recent literature" (1996, p. 341).

However, lack of attention to the social role lies at the heart of opponents' critiques of this view. Many, but not all (Phillips, 1995; Mathews, 1992) of these critics clearly subscribe to social constructivism (Ernest, 1996; Bauersfeld, 1993; Richardson, 1997) or related but distinct (Windschitl, 2002) variants of this form, sociohistorical constructivism (Eisenhart, Finkel, & Marion, 1996), or sociocultural constructivism (Packer & Goicoechea, 2000). Windschitl (2002) explains that while the theoretical frameworks of the variants related to social constructivism are distinct and unique, the principles and implications for the classroom are compatible. Just as he has done, I focused on the similarities that together set social constructivism apart from the two previous constructivist views, yet give each variant some voice to highlight their niche.

### Social Constructivism

Social forms of constructivism give more attention to language and construction of knowledge through relations and interactions. Because distinctions between constructivist views are clearly revealed through argumentative dialogue between texts, I continue with others' critiques of radical constructivism.

Ernest (1996) reproves the radical view not for soundness, but rather for limits in its applicability. The strictest interpretation of the radical view is criticized because "such a view makes it hard to establish a social basis for interpersonal communication, for shared



feelings and concerns, let alone for shared values...[as it erects] barriers between individuals, and between individuals and the social world" (Ernest, 1996, p. 342). For social constructivists, interactions with others are seen as paramount in forming the individual. Knowledge is seen "as having both individual and social components and [social constructivists] hold that these cannot be viewed as separate in any meaningful way" (Windschitl, 2002, p. 137). In this view, "pride of place [is given] to human beings and their language in its account of knowing" (Ernest, 1996, p. 343). The "social construction of meaning" is achieved through a metaphor of "*persons in conversation* [emphasis his], comprising persons in meaningful linguistic and extralinguistic interaction and dialogue" (1996, p. 343 & 342). Embedding the work of Vygotsky and activity theory in his argument, "language is regarded as the shaper of, as well as being the summative product of, individual minds" (Ernest, 1996, p. 343). Vygotsky (1978) conceptualized "knowledge as primarily a cultural product" (Windschitl, 2002, p. 141).

Social constructivists emphasize that development of understanding is facilitated through group work. Some members may know more, which in the context of schools include "more capable peers" as well as the teacher (Vygotsky, 1978, p. 86; Tudge, 1990, p. 157). For Vygotsky, two levels are important to consider for an individual's learning, one "actual" and the other "potential". In between these two levels is the "zone of proximal development [which is] the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (Vygotsky, 1978, p. 86). The type of problem solving task is essential and should consist of meaningful activities such as "conducting scientific inquiries, solving authentic mathematical

problems, and creating and interpreting literary texts" (Windschitl, 2002, p. 141). Activities should be complex, considered too challenging to perform alone, and thus by design the tasks require support (Dixon-Krauss, 1996). Students are supported by their peers when working in groups and also through scaffolding prompts by the teacher. According to Dixon-Krauss (1996), these two characteristics, a difficult challenge and a need for social support, indicate students are working within the zone. Windschitl (2002) described what results from scaffolding understanding in these interactions, "through this assistance the child internalizes the supportive talk and tactics used on the social plane and becomes able to accomplish such tasks independently" (p.141). Working through the zone, the child arrives, in a sense, at the next level, reaching his or her potential.

Eisenhart, Finkel, and Marion embed and extend two forms of constructivism with activity theory, also known as "sociohistorical constructivism [which] emphasizes that knowledge construction, in addition to being active and adaptive work on the part of individuals [from Piagetian and radical views] is historically and culturally constituted" (1996, p. 279). Linked to Marxist theory, activity is conceptualized in terms of doing and self-perception. There is a "material and intellectual" (p. 280) interaction in the process of doing (working, laboring, producing products) and it is the mental reflection on such "activity", that stimulates individuals to think about "social and material conditions" (1996, p. 279). In working with materials, as one learns to produce, one also learns to think. Knowledge of any topic is also shaped by self-identity and the ways in which the self is conceptualized in doing such work (as a laborer, manager, creator, etc.) to achieve a goal.

Another critic of the radical "sect", Phillips (1995), uses a reductionist argument, making atoms and molecules analogous to teachers, parents, and siblings of the external

world, to persuade readers of von Glasersfeld's inconsistency in attempting to recognize an external reality, known only subjectively, and still embrace social influences. Phillips contends that von Glasersfeld's inclusion of the social realm is borne merely out of a matter of necessity, to attend to the pedagogue. Defending his position, and addressing the language component, von Glasersfeld argues that the influence from social interactions on knowledge construction is embraced because others:

have a considerable role in determining which behaviors, concepts, and theories are considered 'viable' in the individual's physical and linguistic interactions with them...[others and society exist] only to the extent to which they figure in that individual's experience—that is to say, they are for each subject what he or she perceives and conceives them to be (1996a, p. 309).

He explains elsewhere (1996b), the external world can show us what ideas "are not viable, but it cannot instruct us what to think...for whatever things we know, we know only insofar as we have constructed them as relatively viable permanent entities in our conceptual world" (p.19). In spite of the claims that some forms of constructivism appear to have dual epistemologies (Phillips, 1995; Packer & Goicoechea, 2000), perhaps there is some consensus even if "the extent of the agreement among the various constructivist approaches is that constructivism is a learning or meaning-making theory" (Richardson, 1997, p. 3).

### Conceptual Change

In considering what learning is and what it means to learn, Ausubel (1968) declared, "the most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly" (in Novak & Musonda, 1991). This tenant is one common thread among forms in the constructivist paradigm (Ernest, 1996), serving as the base for research on learning using conceptual change models, and is a major component of instructional strategies targeting conceptual change in lessons (Driver, 1988) and laboratory

work (Hand & Keys, 1999). It has been commonly accepted for quite some time that individuals have existing ideas from previous constructions (Driver & Oldham, 1986), represented as misconceptions, pre-conceptions, naïve conceptions, or alternative conceptions depending on the author. Constructivists also accept that knowledge is an active process constructed by the individual (Yager, 1991), which can be considered the second common thread. Driver and Oldham (1986) argued for a third thread, that learning be viewed as conceptual change, where learning is regarded as a reorganization of students' conceptions. Constructivists also generally view learning as "the product of self-organization and reorganization" (Yager, 1991, p.55).

For learning to occur, it is also now widely accepted that there is a change in these pre-existing ideas; a sense of newness is implied. In their development of the conceptual change model, Posner, Strike, Hewson, and Gertzog (1982) used analogous reasoning to link science learning to larger scale paradigm changes termed "scientific revolutions" by Kuhn (1970) in the realm of science philosophy. Posner, et al. (1982) claimed that "learning is a rational activity...best viewed as a process of conceptual change" (p. 212). Applying Piaget's terminology in a slightly different way, these authors explain two phases in the process of conceptual change, assimilation and accommodation. When existing ideas are used to deal with new information, assimilation occurs. When new information requires one to discard or restructure existing ideas, accommodation occurs.

The conceptual change model focused on explaining four conditions necessary for the second, more complex phase of conceptual change (Posner et al., 1982). The conditions necessary for most types of accommodation to occur are, (1) dissatisfaction, (2) intelligibility, (3) plausibility, and (4) fruitfulness. The first component, dissatisfaction, is

recognition of a need to change existing ideas, or rather complete conceptual set, because there has been some sufficient reason(s) to deem the current conception insufficient. For the second condition, the new concept for consideration must be intelligible; one must be able to comprehend the idea. This might be achieved in seeing how the new concept relates to experience, facilitated through the use of analogies or metaphors, or through a sense of possibility for the new concept to explain experiences. Belief in the idea is not necessarily required, such as with a science fiction novel (Hewson & Hewson, 1984) or understanding an old scientific theory that has been discarded (Driver & Oldham, 1986). An ability to represent the new idea is considered important as it may help in determining if the "whole" conceptual set was intelligible as opposed to seeing only the "parts" of more complex content. In the third condition, the new concept must be "initially plausible." This condition requires that one believes the concept "to be potentially true, to be consistent with his or her world view" (Hewson & Hewson, 1984, p. 7) and consistent "with other knowledge" (Posner et al., 1982, p. 214), which can include ontological and epistemological commitments, the fundamental assumptions or beliefs that are part of an individual's "conceptual ecology" (Hewson & Hewson, 1984, p. 7; Toulmin, 1972). In the final condition, fruitfulness, the student recognizes the potential for extension in the explanatory power of the new concept, predictive ability, or greater problem solving capability. The fruitful condition for a new concept might also be thought of in terms of offering greater argumentative power.

Hewson and Hewson recognize that "not all learning need be conflict-induced" (1984, p.3). For example, concepts that are not linked but can be merged with other concepts through integration, or differentiation strategies might be used for distinct but related concepts. However, these authors note a distinction between conflict and resolution in three

conditions for conflict. First, the competing conceptions must be intelligible, (2) comparison of two conceptions result in recognition of a conflict and realizing only one is plausible (internally consistent), and (3) resolution occurs either by (a) deciding there are not sufficient grounds for comparison and both concepts are considered plausible in their own right (limiting internal consistency and compartmentalizing knowledge), or (b) determining that one conception is more plausible than the other (embracing generalizability). These authors claim importance of two epistemological commitments; internal consistency is required for a conflict to be recognized and generalizability is necessary for an alternative conception to be rejected. It seems as though to resolve a conflict in the form of choice where one concept is preferred, the learner must be committed to generalize. This is important because it suggests that a change in epistemological and ontological assumptions might need to occur for some accommodations (Posner et al., 1982). Again, some aspects of a conceptual set may be accommodated in part, and the sequence of experiences outlined in the conceptual change model may occur through a non-linear, gradual process.

Agreeing that, in certain situations, conceptual change requires more time, while at other times students may experience gestalt moments, Tyson, Venville, Harrison, and Treagust (1997) further extended others' (Chi et al., 1994) assertions that the nature of the content influences conceptual change, particularly for content specific to one domain. Driver et al., (1994) illustrated this in two cases, which pointed out "different domains of science involve different *kinds* of learning [emphasis theirs]" (p. 11). Since the content in the two cases differed in ontological and epistemological requirements, the authors suggested that the students' own assumptions might complicate learning in a domain. Tyson et al. also suggested the abstractness of a concept might influence the process required to bring about

change. Recognizing conceptual change models have evolved to include social and motivational factors that contribute to learning (Strike & Posner, 1992), Tyson et al. argued for expanding the framework for interpreting conceptual change to include views from ontological, epistemological and social/affective perspectives.

From an ontological perspective, a student's ontological category attached to a concept must match the scientific view, if not, a switch "to the scientifically correct category" is necessary (Tyson et al., 1997, p. 397; Chi et al., 1994). A student working from this perspective looks "out" at "the nature" of the conception under study (1997, p. 398). The authors suggested that addressing concepts such as matter, force and energy from this perspective might facilitate understandings of these and other concepts that are particularly resistant to change. Development is important to consider because attention to metaphysical aspects is thought to increase with age and an individual's intellectual capacity (Tyson, et al., 1997). Driver et al. explain these "everyday ontological frameworks evolve with experience and language use within a culture" (1994, p. 8), which may be one reason why studies with ontological or epistemological components seem to involve older students.

The influence of age on epistemological development is taken as a given by others as well. Similar to the way in which Karplus (1977) argued that Piaget's cognitive stage theory "should not be interpreted as implying that education must wait until development has occurred spontaneously" (p. 174), Roth and Roychoudhury (1994) advised against allowing the assumption to result in adopting a *wait and see* approach. Instead, they suggested that explicit constructivist practices in science might advance constructivist epistemologies in students.

From the epistemological view on conceptual change, the student looks "inward" to examine her own knowledge and assesses such based on commitments (Tyson et al., 1997, p. 400). Importantly, it is often assumed that students partake in comparing the status of conceptions they are learning to their internal milieu; however, few studies have attempted to access and measure this (Tyson et al., 1997). In their qualitative investigation, when students were asked directly to reflect on their epistemologies, Roth and Roychoudhury (1994) found two different positions could be held at the same time, within the same individual. For example, students with an absolute position related to the nature of scientific knowledge, believing laws and theories exist separate from humans could still view science as not entirely objective, recognizing it is based on assumptions and subject to influences from the social world. Albe (2004) reported similar duality in that most surveyed students agreed

*that competent scientists, even if they believe in different theories, will make similar observations, even though at the same time, the students believe that possible reasons for disagreement between scientists are different interpretations, the influence of private companies or governments, moral values, personal reasons and political opinions [emphasis hers]. (p. 4)*

Although retaining two epistemological categories might appear as limiting a commitment to internal consistency (Hewson & Hewson, 1984), Tyson et al. explained how students might benefit:

Initial conceptions, especially those that hold explanatory power in nonscientific contexts, may be held concurrently with new conceptions. Successful students learn to utilize different conceptions in appropriate contexts. That is, the status of one particular conception may change in differing contexts. (1997, p. 402)

Specific to conceptual change research, Qian and Alvermann (1995) found that students' epistemologies predicted learning from a conceptual change strategy embedded in text.

Students with less sophisticated beliefs, considering knowledge as simple and certain, were



less likely to engage in learning from the strategy. An interaction revealed in a study by Windschitl and Andre (1998) indicated students' abilities to learn in certain instructional conditions might be affected by their epistemologies. Students with more sophisticated beliefs performed better under a constructivist approach, which required exploration of a computer simulation through writing predictions, testing hypotheses, and explaining observations. Under the objectivist approach, students wrote conclusions after simulations, which provided confirming experiences, and students with less sophisticated beliefs performed better under these conditions. Classifying students' conceptions according to conditions in the conceptual change model such as intelligibility, plausibility, and fruitfulness is another example of research examining learning from an epistemological perspective (Treagust, Harrison, Venville, & Dagher, 1996).

Viewing conceptual change through a social or affective lens might include investigations of motivation aspects, personal interests and beliefs, strategies facilitating social interactions, as well as arrangement of students' classroom groups and influences from larger cultural contexts. Views from this perspective are likely to reveal elements that certainly influence learning at some point, and might include enquiry into students' attributes (Chambers & Andre, 1995; Hand, Treagust, & Vance, 1997; Roth & Roychoudhury, 1994), or those of teachers (Hand & Treagust, 1995), as well as the community (Haney, Lumpe, & Czerniak, 2003). Although both females and males learn from text-based conceptual change strategies (Andre, 1997), the effectiveness may depend on students' interest levels in the content, i.e. electricity in this case (Chambers & Andre, 1995).

Some research suggests conceptual change instruction might be enhanced through combination with cooperative learning strategies. Students taught cooperative learning

techniques, for example, encouraging participation from group members, paraphrasing others' explanations, and requesting elaboration and justification to support assertions, showed greater achievement gains from conceptual change instruction and used more targeted verbal interactions compared to students who were not taught with the strategy (Lonning, 1993). In results from work with elementary school students' experiences with the concept of balance, Tudge (1990) suggested group arrangement with advanced peers might be insufficient for inducing conceptual change. Rather, to move reasoning forward, students need to be paired with another who uses advanced reasoning with some degree of confidence; otherwise, peers could regress in their thinking. He emphasized that students need to experience the results of their predictions, because feedback, from material in this case, was considered more important than either isolated condition of cognitive conflict induction or group arrangement for work within the zone of proximal development.

In investigating teachers concerns about implementing constructivist practices, Hand and Treagust (1995) found that while teachers were initially concerned about classroom management, after a professional development program, teachers exhibited more student-centered concerns, becoming more aware of how they influence learning and how to better facilitate student participation in science learning through discussion. Identifying potential difficulties teachers may encounter with new approaches can be used to focus future development programs and also serve as a means for assessing the extent to which teachers have already adopted certain elements of constructivism in practice. Studies of teachers trained in such in-service programs become more aware of their roles and responsibilities in their learning and such studies begin to address issues of sociocultural constructivists (Hand, Treagust, & Vance, 1997). In assessing views from the larger community, Haney, Lumpe,

and Czerniak (2003) found that administrators and teachers held more constructivist beliefs compared to students, parents, and community members, indicating a need to expand information surrounding instructional practices to the wider school community.

In a critical discussion of the early conceptual change model, Eisenhart, Finkel, and Marion (1996, p. 276) compared and contrasted three forms of constructivism in terms of the goal(s) for conceptual understanding and motivation to learn. Working from a sociohistorical perspective, they linked the conceptual change model to Piagetian constructivism where motivation to learn is considered within individuals, material and content. They argued against the goal for conceptual understanding from this view that intends "to bring students' emergent understandings into accord with established thinking and practice in the academic disciplines" (p. 276). Conceptual change researchers contend if students "are to accept the scientists' interpretation of the phenomena, they might have to change their minds in ways which may well require restructuring of their existing conceptions, rather than simply adding new knowledge" (Hewson & Hewson, 1988, p. 597). Windschitl (2002) also explained this goal "is to help students move from their inaccurate ideas toward conceptions more in consonance with what has been validated by disciplinary communities" (p. 140). Authors taking the sociohistorical approach reveal an aversion to conceiving conceptual change as requiring an epistemological shift toward an authoritarian view, and lean more toward knowledge restructuring that makes sense to the individual, facilitated by social interactions.

These authors recognized that with radical constructivism, the end in terms of conceptual understanding is seen more openly, "in which students have developed and can defend adaptive scientific understandings that may or may not correspond to established

views" (Eisenhart, Finkel, Marion, 1996, p. 278). Radical constructivism shifts the goal for conceptual understanding from an emphasis on correctness and an authoritarian source to a view that recognizes knowledge as an organization of personal experiences (von Glasersfeld, 1983); and explanation as an individual's formulation, constructed in a way that makes sense and is useful to that individual (Eisenhart et al., 1996; Driver, 1988). Motivation is still seen as located in the individual and materials. The problem with both Piagetian and radical constructivist views according to Eisenhart et al. is that neither "challenges the collective means of viewing and manipulating the world that preserve the status quo in schools or in science" (1996, p. 278). For example, social and class differences can be reproduced in the classroom when materials or the teacher are perceived as authoritarian (Richardson, 1997).

On the other hand, sociohistorical constructivists view learning from a wider perspective in addressing the external elements that form and shape what people do as well as their thoughts and feelings. Motivation to learn is considered "in the structuring resources (nature of the work to complete, appropriate discourses, relevant goals) and opportunities to form mature identities" (Eisenhart et al., 1996, p. 276). Motivation "depends on the availability of an 'authentic context'" (Eisenhart, Finkel, Marion, 1996, p. 280) through a realization of identity (see also Hanrahan, 1999). Learners see potential for themselves, a place, in working with discipline related issues in the future. This view calls for a broader interpretation of science literacy that requires development of "different mediational tasks [genres, work procedures], tools, and identities" (Eisenhart, Finkel, Marion, 1996, p. 281). These authors promote curriculum composed of problem-solving activities with strong science content, situated in local contexts, and requiring socially responsible applications of science. They advocate these types of activities, arguing they are better suited functionally

for a move toward a broader conception of science literacy with more potential to reinforce democratic ideals. Quality testing and composition analyses of local water sources is one example of an extended activity, situated in a meaningful context, that can engage students with science content and offer experiences for students to envision themselves as problem solvers addressing concerns relevant to their community.

From a sociocultural perspective, Packer & Goicoechea (2000) contend that their view differs from Piagetian constructivism in ontology as well as epistemology, which is revealed through an analysis of identity. They labeled psychological researcher's conceptions of identity as epistemological, whereas sociocultural conceptions are more fluid in their interpretations of identity seeing it as "closely linked to participation and learning in a community" (p. 229). Basically, what philosophers of the sociocultural view maintain, is that identifying oneself, as a self, is a societal construct. Packer & Goicoechea (2000) explain, "the human person is not a natural entity but a social and historical product" (p. 231). In ontological terms, they argue that knowledge, including knowledge of self is constructed and "what counts as real varies culturally and changes historically" (p. 232). What one comes to know as self, an individual separate and unique comes from society. Identities are shaped through community participation, and as such, participation and emerging identities can act on the community as well as shape or transform it. Learning is considered "an integral part of broader ontological changes that stem from participation in a community" (p. 234). This is important for them because "a failure to learn can be reinterpreted as a struggle for identity" (p. 235). Compared to Piagetian constructivists who view cognition as a subjective activity separate from an objective world, sociocultural constructivists' "ontology envisions a practical process of construction where people shape the social world, and in doing so are

themselves transformed" (p. 234). In summary, they argue, "community membership sets the stage for an active search for identity, the result of which is that both person and community are transformed. Learning entails both personal and social transformation—in short, ontological change" (p. 235).

What is of particular importance here, von Glasersfeld (1993) explains, is that social constructivists "tend to take society as a given, and a radical constructivist cannot accept this. From my point of view, 'society' must be analyzed as a conceptual construct before its role in the further construction of concepts can be explained and properly assessed" (p. 24). It seems that this is the fundamental purpose of viewing from a socio-historical or socio-cultural perspective, to bring society, its issues and influences to students' attention, into their consciousness and classroom repertoire of experiences. Nevertheless, as with the assumption that age and development play an important role in addressing metaphysical aspects (Tyson et al., 1997), age, development and the experiential resources that result from such, should also be considered for their potential influence on students' abilities to attend to the notion of society and societal constructs.

Addressing the duality contention, von Glasersfeld reminds readers that no philosopher in the course of history has been able to deny, "that the real world, in the sense of ontological reality, is inaccessible to human reason" (1996a, p. 309). To deal with this "impasse," radical constructivists use an epistemological process description to "change the concept of knowledge" and do not deal with ontological matters (von Glasersfeld, 1996a, p. 309). Social constructivists, such as those above, Bauersfeld (1993), and others retain and integrate tenants of radical constructivism while attending to social dimensions that influence learning in the classroom and elsewhere (Ernest, 1996). Other theorists have taken a slightly

different integrative approach, synthesizing various views to take an interactive-constructivist perspective.

#### Interactive-constructivist Perspective

The interactive-constructivist perspective has clearly emerged out of necessity. Henriques (1997) attributed the interactive constructivist perspective to Yore and Shymansky (1991) among others. Several authors (Driver, Asoko, Leach, Mortimer & Scott, 1994; Tobin & Tippins, 1993) have called for a synthesis of views, "claiming that knowledge is personally constructed and socially mediated" (Windschitl, 2002, p. 137). These authors recognize that while knowledge exists in the mind of an individual, individuals "only exist in a socio- cultural sense...[knowledge is constructed] in the presence of others...When a learner thinks in terms of language, the thinking is a social process even though it is occurring within the mind of a single individual" (Tobin & Tippins, 1993, p. 6). Interactive-constructivists merge these views as both personal and social perspectives on learning "are necessary in interpreting science learning in formal settings" (Driver, Asoko, Leach, Mortimer & Scott, 1994, p.5). Take, for example, the explanation formulated in applying the interactive constructive model to reading science text. Yore, Craig, and Maguire (1998) explain that while the model recognizes a need for social interactions, it is based on the assumption "that actual learning is a private action not totally explained by the community interactions and group level consensus (McCarthy & Raphael, 1992)" (1998, p. 28). Building on the work of Henriques (1997), Yore (2001) thoroughly presented the "face" of interactive constructivism; many of these categories are revealed in this section in an attempt to justify what might otherwise appear as a bit of a conundrum.

As does the modified relativist ontology of social constructivism stem from recognition the world exists "out there supporting the appearances we have shared access to, but we have no certain knowledge of" (Ernest, 1996, p. 343), so too is this held in the ontological hybrid of interactive-constructivism. Driver & Oldham (1986) explained the dominant view of science among philosophers is that while knowledge of the external world is directly inaccessible, rational criteria are generated from scientific practices, which are based on realism. However, not all there is to know about this external world is known and as such, "we may always be wrong. Thus...one must be a realist ontologically to be a fallibilist epistemologically" (Manicas & Secord, 1983, p. 401). Again, the ontological hybrid of interactive constructivism emerged from necessity. In a manner akin to the epistemological process description von Glasersfeld used to change the concept of knowledge, Hand (2004) explains the interactive-constructivist perspective recognizes two types of knowledge, public and private. The public realm is constructed through interactions with the physical and social world; the private component results from activities purely individual, such as meaning making that results from personal reflection on these interactions (Henriques, 1997).

At this point, a reminder is in order concerning the dual epistemologies inherent in weak constructivism. According to Ernest, this view accepts an objective knowledge realm, in recognizing truths and facts. But at the same time it holds that all knowledge is individually constructed and in this way "only tries to account for the knowledge representations of individuals. This is quite legitimate, for not all theories can be theories of everything" (1996, p. 340). Interactive-constructivism also recognizes the potential of this traditional epistemology to influence goal pursuits in the public realm that make up the



scientific body of knowledge, proximately, and the private realm, through individual scientific inquiry investigations, ultimately. For example, experimental design, at this time within the scientific paradigm, attempts to alleviate the influence of variables and approach objectivity. The degree to which objectivity can ever be achieved is largely dependent on the materials or subjects of the investigation and the ability to control external variables.

Generally, it is more common to recognize such potential in physical and chemical disciplines of science, when concrete observations are made and controls in experiments are more likely accepted. For example, control of outside variables is considered more achievable in these types of experiments, compared to broader contextual investigations in social and environmental disciplines of science, which are potentially more susceptible to influence from external factors. However, should objectivity ever be "reached," it could only be deemed so through interactions with others in the public realm (social influence) and again, through subjective interpretation by the individual investigator. Opponents point to the subjectivity of all human experience, which makes objectivity impossible. One can consider an attempt objective, because the individual constructs knowledge, but any consideration is constrained by others in the public realm, some may either concur, or more likely accept with reservation, recognizing the limitations of an objective claim. For the interactive constructivist, Yore (2001) explained the epistemic view of science as evaluativist in a modernist tradition.

The evaluativist criteria for science interactive constructivists subscribe to parallels modern philosophical views of the nature of science. Phillips (1999) explained this epistemological position through reference to Popper (among others) and nonfoundationalism, which he linked to empiricism in as much as proponents seek

justification through experiences, such as empirical evidence, but at the same time recognize that observations are dependent on theory and current knowledge of the observer. The "theories or hypotheses that have been adequately tested are tentatively accepted as knowledge – with the caveat that no knowledge is ever absolutely established" (Phillips, 1999, p. 252). He argues that the notion works in science because (1) it allows for laws constrained by ideal circumstances, which cannot be verified for all time and space because observation of all time and space is implausible and (2) it allows also for unobservable entities such as in theoretical physics, which cannot be verified through experience (Phillips, 1999). Attempting objectivity, forever constrained by subjective experience, summarized in von Glasersfeld's terms, is accepted as the most viable view at the moment. To this end, interactive constructivism emerges from the dilemma of weak constructivism in doing precisely what Ernest (1996) recommended by acknowledging "that there is a pregiven world of persons, objects, and conventional knowledge (after all, denying this is problematic), [but also adopting] an agnostic, tentative position about our knowledge of this world" (p. 340). And as a result, interactive-constructivism matches "the position of virtually all schools in the modern philosophy of science" (p. 340).

The epistemological hybrid of interactive constructivism is further clarified in conceptualizing an example from a model of multiple worlds. The framework provided by this view is an opportunity for science teachers, students, and educational researchers to merge three different worlds. The model proposed by Popper and Eccles (1977), was adopted by Keeves (1999) to provide context for social inquiry and educational research and to justify the apparent lack of universal generalizations generated from such endeavors. In the worlds model, "the real world" consists of the physical, such as material objects. The

second, "learner's" world, houses subjective mental states, both conscious and unconscious. The third world, "body of knowledge...has been created as a new objective world, that is the product of human minds...[including] propositional knowledge concerned with causal explanation,...art, music and literary writings that are all part of the world of shared knowledge...[and here] objects have acquired a reality of their own" (Keeves, 1999, pp. 4-5). Under the worlds model, the body would be housed in the physical world, science content in the shared world, and constructed understandings of science in the learner's world. As understanding develops through an interaction between a shared body of knowledge (public knowledge) and an individual's subjective experience (private knowledge), the learner in the physical world is transformed (Keeves, 1999). An interaction between worlds changes the composition of those worlds. Even abiotic objects of the real world are thought to undergo change, for example through degradation. Although, as Keeves points out, this change is comparatively much slower than change experienced by humans. It is these transformations of materials in the physical world, potentially influencing the shared body of knowledge world that is recognized in the tentative, evaluativist view of science from the interactive constructivist perspective. These transformations, on a comparatively accelerated scale considering the human component involved, are also responsible for the apparent lack of universal laws in educational research (Keeves, 1999).

Considering the interactions between each of the three worlds, the worlds model not only exemplifies the practical relevance of interactive constructivism for the classroom, but also provides some justification for merging qualitative and quantitative methods for the research in this dissertation. I apply Keeves' (1999) argument first to the individual researcher, then extend to group research, although it should be noted he originally used the

argument to suggest both scientific and humanistic approaches are appropriate for educational research. For example, if the goal of the researcher is to add to the shared body of knowledge world, by looking at interactions between the real world and the learners' worlds, from her own perspective as an individual in the learner's world, then there are two, two-way interactions. The investigator is a mediator at the center of the interactions, an arrangement that serves to justify a merged approach. In the studies enclosed, the examinations include more than one investigator; thus, individuals' perspectives merge at the center to look out at the interactions between learners' worlds and the real world. The second interaction, attempting to add to the shared body of knowledge world, from a vantage point of informed consensus, might also suggest an additional strength. When theories are tested against evidence in the interaction between the shared body of knowledge world and the real world, "the epistemological basis of this process does not differ whether quantitative or qualitative methods of inquiry are employed" (Keeves, 1999, p. 12). Guba and Lincoln (1999) concur that both qualitative and quantitative methods can be used to inform the same investigation. Their argument for separation lies at the level of the paradigm, for which they make an epistemological case for distinguishing pursuits of knowledge between naturalistic and scientific (or rationalistic) studies.

Although at different level and extent, both qualitative and quantitative methods result in products that can inform education, in the shared body of knowledge world. One could conceive of the information available for education, in the shared body of knowledge world, as a pot from which to take away either a qualitative portion or a quantitative portion, and then merging each of these separate pieces to inform the self. On the other hand, one could conceive of a pot made from three different samples, qualitative investigations,

quantitative investigations, and mixed-methods research. In this pot, mixed method research offers a portion that has already been integrated. In a sense, withdrawal of this portion represents one piece composed of both. The strengths of such work might be represented through a genetic analogy, possessing a sense of hybrid vigor.

The research methodology from an interactive constructivist view in education, while reflective and modest, matches the epistemic view of science (Yore, 2001) and is eclectic in that it is also subject to evaluativist critique with modernist criteria. Hand (2004) explained the evaluativist view of science accepts that science is creative, but holds that it is constrained by the nature of the physical world and is subject to public critique. Scientists must be able to defend their ideas to the public (Bazerman, 1988). Such critique stems from the modernist position requiring claims, justification, and evidence, which are also nature of science components. Interactive constructivist research is scientific in as much as it evaluated with modernist criteria and only in so far as the public critique accepts that the focus of the investigation is within the realm of science.

Constructivism, as a term applied to educational research, takes on a different representation, as a metaphor for learning. Differences between constructivism and the pursuit of truth in the sense of God and absolute truth, or truth as the one correct representation of reality in the hermeneutic approach, lie in methodology (von Glasersfeld, 1993). Objectivity is not a claim of constructivists (Tobin & Tippins, 1993; von Glasersfeld, 1993). In constructivist research, "data are not collected but are constructed from experience using personal theoretical frameworks...the assertions of one study become a part of the knowledge base and are incorporated into the plan for the next study" (Tobin & Tippins, 1993, p. 15 & 16). The purpose of constructivist research "is not to convince readers of the

generalizability of what has been learned but to provide sufficient details of the contexts in which the theory is embedded" (p. 19) for readers to interpret and use. In this way, constructivism is seen as a metaphor for learning through research. Literacy researchers also apply the term as a "metaphor for the active and authoritative processes of readers and writers" of mature students who construct and represent ideas in text and identities in sociohistorical contexts (Greene & Ackerman 1995, p. 383). In the realms of research in "psychology or education, taking account of the subjective nature of experiential realities becomes a matter of honesty" (von Glasersfeld, 1993, p. 29) and perhaps even one of obligation.

In summary, distinctions were highlighted between four forms of constructivism, weak, radical, social and interactive. Education can progress through such theoretical debates (Ernest, 1996), even if the pragmatic outcome is only eclectic. A case was made for adopting the interactive-constructivist perspective for the research in this dissertation as it matches current views in modern philosophy of science. Epistemological differences between the constructivist forms are thought to "make a significant difference in practice" (Ernest, 1996, p. 337). Similarly, successful constructivist approaches are thought to depend on epistemology as these fundamental assumptions have "covert" functions in the classroom and also influence teachers' reflections (Bauersfeld, 1993, p. 467). Thus, in the next sections, the components of these various views as they apply to science education in particular and constructivist practices in general are discussed.

### Constructivist Science Teaching and Learning

The various forms of constructivism are useful tools for teacher reflection; these frames can provide theoretical and practical justification for teaching approaches (Yore,

2001; Tobin & Tippins, 1993). As with science literacy views and goals, teachers are faced with the challenge of interpretation and decision making as to how one or more of these various views can inform and influence practice. The process of adaptation, application, and implementation of constructivism can result in dilemmas for teachers (Windschitl, 2002) and students, particularly when students' epistemologies differ to that of the teacher (Roth & Roychoudhury, 1994). Richardson (1997) proposed another challenge in becoming a constructivist educator was in developing "an approach to teaching that does not contradict the content of the course" (p. 11). For her, the type of constructivism employed depends on the subject matter. Also arguing the nature of the knowledge is important to consider in teaching and learning science in particular, Driver et al. (1994) explain scientific concepts as "constructs that have been invented and imposed on phenomena in attempts to interpret and explain them...[which are] unlikely to be discovered by individuals through their own observations of the natural world" (p. 6). In viewing knowledge in science as constructions, these authors also maintain an ontological element of realism put forth by Harré (1986) that such "knowledge is constrained by how the world is and that scientific progress has an empirical basis, even though it is socially constructed and validated" (Driver et al., 1994, p. 6). These notions are incorporated in the interactive-constructivist position; the pedagogical practices emphasized within, inquiry, social negotiation, argumentation, and writing reflect the discipline and remain true to the basic tenants and principles of constructivism.

While applying a constructivist philosophy to teaching a discipline such as science that by nature embraces a realist view may seem contradictory, it does not need to be. Constructivist principles "are not at all inconsistent with the view of science as an active pursuit" (Julyan & Duckworth, 1996, p.71). In the constructivist view, "learning is an active

process occurring within and influenced by the learner as much as by the instructor" (Yager, 1991, p. 53), so there is a match to the first basic tenant of constructivism. Although Lederman and Flick (2004) caution readers to avoid the assumption "that a constructivist teaching approach will lead students to a constructivist view of the discipline they are studying" (p. 54), Roth & Roychoudhury (1994) argue, "the way the nature of knowledge is presented over the years of schooling is likely to affect students' understanding of it" (p. 6). Importantly, the effectiveness of such an instructional approach may be dependent on students' epistemological beliefs (Windschitl & Andre, 1998) as well as that of the teacher. Some authors contend it is important for students' and teachers' epistemologies to match that of the discipline (Roth & Roychoudhury, 1994; Posner, Strike, Hewson, & Gertzog, 1982). Others argue that students' alternative conceptions have purpose and place in social situations outside of science and that these ideas should not necessarily be discarded, but rather offer an opportunity to explore understandings of the nature of science, for example, in examining what constitutes a scientific theory (Driver et al., 1994).

What students learn about the epistemology of the discipline "is dictated more by what is addressed specifically about the discipline's epistemology than by the epistemological basis of the pedagogy enacted" (Lederman & Flick, 2004, p. 54). There is a place for acceptance of this claim in the interactive constructivist view, which allows for the use of direct instruction when there is a need (Henriques, 1997). However, teachers would not rely solely on this mode, particularly in dealing with complex topics, because some ambiguity might remain for students. Explicit instruction does not ensure understanding. Rather, it should be used "to enhance and promote oral discourse and argumentation embedded in science inquiry" (Yore, Bisanz, & Hand, 2003, p. 712).



In a related argument, Lederman & Flick (2004) caution readers to avoid the presupposition "that students learn about nature of science and scientific inquiry just by doing science" (p. 55). Some elements of the nature of science, such as its tentativeness, remain underdeveloped even in a laboratory setting (Lederman & O'Malley, 1990). Agreed, simple exposure to an experience of learning in a constructivist environment in which the epistemology remains implicit may not be enough. Also agreed, subject matter, including components of the nature of science, deserve place in instruction. The point here is that multiple modes of learning enacted under a constructivist framework best reflect and support the scientific endeavor. Roth and Roychoudhury (1994) suggested that the way the pedagogy materializes, such as in constructivist learning environment consisting of collaborative work, discussion, negotiation, and an open inquiry focus in labs, can "foster a constructivist epistemology" better than laboratory experiences that require students to follow prescriptive procedures (1994, p. 27).

Learning viewed through a constructivist lens and the teaching that follows is perhaps a better way to conceive of the scientific discipline and present science content, (in as much as it would be "presented" in the traditional sense). Windschitl (2002) argues that while constructivism is a theory of learning rather than of teaching, teachers need to internalize an epistemology of learning that reflects tentativeness, consistent with von Glasersfeld's view of constructivism. Students experiencing science with a teacher who espouses constructivism and utilizes multiple strategies might better understand components of the nature of science, such that it is open to change. While most science education researchers are thought to agree on this aspect (Lederman, 2001, as cited in Yore, Bisanz, & Hand, 2003), students do not always recognize the general tentativeness of science. Students see inconsistencies in media

reports of science, which is primarily how they are exposed to research outside of the classroom throughout the year. Interpretations of these reports lead to observations such as, "what caused cancer one day they don't think causes it anymore," and to conclusions, "everything causes cancer." The point here is that the tentative nature and uncertainty principle apparently conflict with its authoritarian reputation. The question becomes, when do these same students come to an understanding of how such pursuits can result in contradictory reports and at the same time develop an appreciation for how similar methods of science have resulted in establishing knowledge that is generally accepted?

For von Glasersfeld (1993), this comes down to an issue of perception and what people notice and think about their experiences, as "we have no way of knowing what is or could be beyond our experiential interface" (p. 26). Predictions in science are predictions based on experiences. What one accepts and realizes from those experiences are influenced by the methods and means of chosen for testing, which define those experiences. These choices are made based on expectations of what information might be gained through experience. Thus, "if a prediction turns out to be right, a constructivist can only say that the knowledge from which the prediction was derived proved viable under the particular circumstances of the case" (p. 26). This view is in line with scientific thinking and extends to experimental design where potential variables are held constant as different outcomes might be obtained under circumstances where another variable was introduced.

In commenting on the appropriateness of an ability to reject or accept another scientist's hypothesis, von Glasersfeld explains that while "experiential worlds belong to individuals...these individual worlds become adapted to one another" through social interaction and can result in consensus (1993, p. 28). Consensus does not imply that the

ideas are "identical", only that there is no present way to see how they differ (p. 35). This too, is in line with the nature of science. Conceding to the assertion that "there is more to a scientific theory than social agreement" in attempting to explain learning of complex material (Hewson & Hewson, 1984, p. 2), in science, developed theories tend to be "accepted," until evidence is accumulated otherwise (Kuhn, 1970). For constructivists, "science does not exist as a body of knowledge separate from knowers...[it] is viewed as a set of socially negotiated understandings of the events and phenomena that comprise the experienced universe" (Tobin & Tippins, 1993, p. 4). For radical constructivists, such as von Glasersfeld, the realist perspective of many scientists is valid in as much as it is another way of constructing epistemology and is fine in as much as it is not purported as something others must subscribe to. For him, discarding the notion of truth as what others *must* believe would result in a "more livable and fruitful...cultural and social reality," a condition achievable when teachers carry out "duty," which is "to proclaim the 'tentativeness' of everything one teaches," and to present the likeliness that information will be considered differently in the future (1993, p. 32). Such changes in ideas not only result from accumulation of scientific knowledge but are also influenced by technological advancements that offer new means to perceive and experience the world, new and different people entering into scientific fields, and a continual flux in larger societal goals and problems (Kuhn, 1970; Tobin & Tippins, 1993).

A sense of humbleness in acknowledging different conceptions to explain the world exist might support and perhaps even better facilitate a willingness to accept the idea that science is tentative. Openness to the notion of change paves a path for continuous knowledge development. Within here too lies the important element of respect. Respect for alternative constructions is conveyed through recognition that different perceptual

experiences (von Glasersfeld, 1993) can result in unique ways of constructing understanding for students (Julyan & Duckworth, 1996). Thus, the issue of respect is central to two tenants of constructivism, all of which reflect values that are consistent in general constructivist pedagogy.

### General Constructivist Pedagogy

Constructivism, for the teacher, is a learning theory with explanatory power, and as such is best conceptualized as a "set of intellectual referents" (Tobin & Tippins, 1993, p. 7) from which to tap in making decisions about practice. Constructivism in this way serves "as a tool for critical reflection" to guide further teaching and learning (1993, p. 8). Adopting a constructivist lens does not imply allegiance to a particular method set, as there is no specific procedural sequence for the pedagogue to follow (Driver et al., 1994; Millar, 1989). The theory more clearly informs the teacher what to avoid (von Glasersfeld, 1996a). This section presents general principles that guide the constructivist teacher in selecting instructional strategies and highlights attributes of the interactive-constructivist position.

Brooks and Brooks (1993) presented five guiding principles of constructivism: (1) posing problems that are or will become relevant for students; (2) centering learning on unifying, or primary concepts; (3) eliciting students' conceptions and addressing these various views in instruction; (4) using the first three principles as a guide for "adapting curricular demands to students' suppositions" (p. 72); and (5) "assessing student learning in the context of teaching" (p. 85). Content of the problems, the curriculum, and activities should be interesting, engaging, and provide "a variety of avenues for exploration" (Julyan & Duckworth, 1996, p.71) as well as "a variety of sensory experience from which learning is built" (Tobin & Tippins 1993, p. 7). Two activities of primary importance in constructivist

pedagogy are physical experiences and social interactions (Tobin & Tippins 1993; Driver et al., 1994).

Instructional design from the interactive constructivist position (Henriques, 1997) has the following attributes as it: (1) aligns goals, instruction and assessment; (2) centers on unifying concepts and principles; (3) emphasizes major skills and habits of mind for science literacy in activities, during these students are actively constructing knowledge by accessing, engaging, experiencing, exploring, integrating, consolidating, applying, thinking critically, developing and communicating arguments, explaining, justifying, rationalizing, and persuading; (4) embeds direct instruction in a context of need; (5) focuses on learning growth in conceptual change and metacognitive aspects; (6) and utilizes multiple strategies and sequences, such as guided inquiry, learning cycles, conceptual change models, social negotiation, and argumentation.

Purposeful, strategic choices are made in designing and implementing lessons, which are composed with intention for a specific direction (lesson goals). However, the goal itself at times could be an entirely open, because through exploratory experience, where individualized pursuits are primary, the ultimate direction may be unknowable. At the same time any plan is flexible as it materializes because the teacher is aware and responsive to students' needs and modifies the lesson or subsequent lessons according to those needs. In this way, there is recognition at the start that the intended path may diverge.

In practice from the interactive-constructivist position, efforts are made to make the private component of knowledge, inner speech, public (Yore, 2001). In the process, alternative ideas are surfaced, shared and clarified. Pedagogical features of this position include shared control, a greater emphasis on the consolidation phase, and a focus on

developing scientific arguments. Students perceive a sense of shared control because their ideas, voices and efforts remain central in lessons as meanings are negotiated publicly (Shymansky, 1994; Yager, 1991); and personal responsibility for learning is emphasized as active construction of knowledge is private and meaning making is ultimately individual (Driver & Oldham, 1986; Henriques, 1997; Yore, Craig, & Maguire, 1998). When students have the responsibility for their learning, in that they make decisions about what they know and how to represent their knowledge, there is a sense power transfer from the teacher to the student (Tobin & Tippins, 1993). With power and control comes responsibility. The shift of these elements to the student also re-centers the motivation to learn.

In Table 1, I collapsed Yore's (2001) linguistic discourse category into the motivation category from Eisenhart et al. (1996). In doing so, I suggest that the function of discourse in the interactive constructivist classroom matches an intrinsic desire individuals have to learn, which in this sense is a search for clarity by the individual in tapping elements of the shared knowledge world. Here I am not suggesting that all students have equal motivation to learn any one topic just that they all have an intrinsic desire to learn. Whatever is learned is achieved ultimately through knowledge constructed by the individual, through interactions with the physical world, composed of objects and materials (as in hands-on learning investigations) as well as other individuals. Meanings are negotiated through interactions with others, exchanging and entertaining alternative ideas and explanations of events (seeking). Meanings are also negotiated with the self in interacting with the physical world, for example, again with objects and materials in investigations, reading text, and constructing text through writing (all doing). Again, learning from this view is considered largely a social experience, although ultimately determined by the individual. The purpose of the discourse

is to share alternative conceptions to foster and understandings, but again, consensus is not required because the content of the shared discourse is assessed based on scientific canons rather than agreement (Yore, 2001; Hand, 2004).

Although common to all forms of constructivism, because discourse is an essential instructional approach from the interactive perspective, two teacher behaviors are particularly important to avoid. The first common behavior cautioned, is reliance on the sole use of targeted questions, with a single answer, especially when the teacher is compelled to respond with "no" or "you're incorrect." Such dialect serves to stunt students' thinking, discourage students from sharing explanations, and limits students' creativity (Brooks & Brooks, 1993).

Another behavior to avoid in interacting with students is the tendency to classify students in terms of Piagetian stages, for example, as having the capacity for either concrete or formal operational thought. Students' reasoning patterns will not likely fit neatly into either category when considered within their full behavioral repertoire (Karplus, 1977). According to Brooks and Brooks (1993), "several different cognitive structures" are available for students, and it is the "décalage,...the gap between an individual's use of a cognitive structure in one domain and lack of immediate transfer of that structure to other domains," (p. 71) that is of greater utility for informing instruction. Karplus (1977) argued that it is more important to determine the kinds of reasoning patterns necessary to understand particular science concepts and to "help students develop more advanced reasoning patterns than they use currently" (p. 172). Understanding of concrete concepts is facilitated by observation. Understanding of formal concepts, such as gene and chemical bond, is often dependent on understanding the definitions of "other concepts, abstract properties, [or] theories" (p. 173). Lemke (1990) concurred and Halliday (1993b) further explained

the difficulty lies more with the grammar than with the vocabulary...it is the total effect of the wording...the problems with technical terminology usually arise not from the technical terms themselves but from the complex relationships they have with one another. Technical terms cannot be defined in isolation; each one has to be understood as part of a larger framework, and each one is defined by reference to all the others. (p. 71)

To facilitate understanding, the constructivist teacher has several strategies from which to choose. The Learning Cycle, as described by Karplus (1977) for high school students, consists of three stages, 1) exploration, 2) concept introduction, and 3) concept application. In the first phase, students explore a new situation and learn through interactions with materials and the environment. In this initial stage, the teacher might expect students to observe particular phenomena and possibly, that the experience will cause questions or result in disequilibrium. The teacher offers little to no guidance or direction. Instead, the teacher becomes the learner, closely monitoring what students are experiencing, and on occasion might pose a question concerning what students are doing, why it is being done, or what happened as a result of exploring (Baker & Piburn, 1997; NRC, 1996). In the next phase, terms and concepts are defined. This phase might involve direct instruction through a lecture. Or through a more student-centered approach, in which ideas are elicited through discussion and students are encouraged to formulate their own explanations, developing the concept's boundaries for themselves. Analogies, metaphors, and models are useful tools in helping students develop new conceptual frameworks. In the last phase, students apply the concept or reasoning pattern to a new situation, which is now more structured based on the concepts and terms introduced. Application activities might be proposed by the teacher or designed by the students (Baker & Piburn, 1997).



The previously mentioned Conceptual Change Model has also been recommended. Teaching sequences under this model include acknowledging prior ideas and alternative conceptions exist, eliciting and using these as a diagnostic tool not only to assess students' thinking, but also to inform subsequent lessons (Ausubel, 1968, Driver & Oldham, 1986; Hewson & Hewson, 1984; Posner, et al., 1982). Attention to prior knowledge is a basic tenant of constructivism (Tobin & Tippins, 1993). Students are encouraged to become active in the learning process, another basic tenant of constructivism. Learning outcomes are conceptualized as "an interactive result of what information is encountered and how the student processes it based on perceived notions and existing personal knowledge" (Yager, 1991, p. 53).

One such instructional sequence recommended by Driver & Oldham (1986) consists of five phases, orientation, elicitation, restructuring, application, and review. The first phase, orientation, is used to reveal the purpose and develop motivation to learn the topic. In the next phase, elicitation, students express their existing ideas. In the restructuring phase, the existing conceptions made public and constructed meanings are evaluated through discussion where language is clarified and conflicts are explored. Experiences stimulating cognitive (Posner et al., 1982), or conceptual conflicts (Hewson & Hewson, 1984) are also possibly introduced. These discrepant events (Nussbaum & Novik, 1982) are disconfirming experiences that serve to compel students to think about the implications of their ideas, which might also include designing experiments to test ideas. In the application phase, new ideas are consolidated and reinforced by relating them to what is known as well as using them in new and different ways, which again might include further investigations. In the final review

phase, students focus on their own thinking, reflect on their initial ideas, compare these to recent experiences, and identify how their ideas have changed.

In strategies with conceptual change focus, elicitation of students' current conceptions allows the teacher to become familiar with where students are in the process of understanding a particular topic. Revealing prior knowledge also provides information concerning how students currently relate concepts within the topic. Exploring beginning ideas is in this way a window into students' thinking, and for the teacher this "opens the way to explaining why a particular answer may not be useful under different circumstances" (von Glasersfeld, 1993, p. 33) or might be "viable but perhaps limited in its applicability" (p. 34). The teacher's role is to provide opportunities for students to realize "that their conceptions have limitations and that there are situations where those conceptions do not work" (von Glasersfeld, 1993, p. 31). The situation is similar to discarded theories in science, which "are not proven to be 'wrong'; they merely turn out to be inadequate" (p. 35). To change their ideas, students need to realize what is inadequate and why it does not work. According to von Glasersfeld, "the teacher must have an almost infinitely flexible mind" (p. 33) to appreciate the variety of students' thinking, where they are at present, and the different paths each student might take, all of which can then be used to "orient the students' constructing in a fruitful direction" (p. 34).

A constructivist teacher may still act in authoritarian ways (Windschitl, 2002; Driver, et al., 1994), but the regime itself has changed in the constructivist classroom compared to the traditional classroom. Students' momentum is not halted by authoritarian directive, but instead their thinking is stimulated to entertain alternatives and reflect on the viability of their own thoughts. The teacher is no longer the intellectual gatekeeper, but rather, is seen as a mediator (Driver, et al., 1994), assisting students "in learning what is currently regarded by

society as viable knowledge" (Tobin & Tippins, 1993, p. 5). The role of the teacher is "to monitor learning and to provide constraints so that student thinking will be channeled in productive directions" (p. 10). Instead of dictating, the teacher models scientific thinking, but can still demand "consistency among beliefs and between theory and empirical evidence" (Posner, Strike, Hewson, & Gertzog, 1982, p. 226). In this way, the teacher is more of a guide to help students establish criteria for evidence (Windschitl, 2002) and articulate their claims, assertions, arguments, and evidence "to help them to make personal sense of the ways in which knowledge claims are generated and validated" (Driver, et al. 1994, p. 6). The teacher is also expected to model inquiry, interest and enthusiasm for the scientific discipline, and respect for alternative ideas (NRC, 1996) as she or he acts to scaffold the development of arguments during discussions and in writing.

The teacher's role as a life-long learner is essential (Driver et al, 1994). With this attribute, the teacher recognizes some tentativeness and uncertainty exist for all learners and sometimes "'not knowing' is a state that is important to live with" (Julyan & Duckworth, 1996, p.71). The teacher acts as learner by continuously accessing information about students during a lesson (Brooks & Brooks, 1993), professional knowledge related to the teaching in general, (pedagogical knowledge), information about strategies particularly useful for teaching in their discipline (pedagogical content knowledge), as well as the content of the discipline they teach (Shulman, 1986). Shulman (1987) contends, "teacher comprehension is even more critical for the inquiry-oriented classroom than for the didactic alternative" (p. 7).

Conceiving of language as a tool (Emig, 1977) serves a variety of functions.

Language is a tool and a technology in science (Martin, 1993) used to think, reason, problem-

solve, and communicate with others to take informed action (Yore, Bisanz, & Hand, 2003). From a sociocultural perspective, the primary mechanisms of language use, reading, writing, talking and listening are each considered tools in their own right "for engaging in and making sense of social practices" (Moje, 1996, p. 175), which in doing help learners to understand the social world. Others have argued it is important for the teacher to understand "how language is used within the disciplines as a tool for communicating and negotiating ideas" (Windschitl, 2002, p. 147), its functional value, that is, how the language works in representing a scientific "construction of reality" (Halliday, 1993a, p. 68).

### Language

Language is central to understanding science (Halliday & Martin, 1993; Yore, Bisanz & Hand, 2003; Lemke, 1990). Language is key, particularly in learning science because the nature of the language is complex. While this is one particular view, the purpose of this section is to present the reasoning behind the contention that the language of science is conceptually complex. In addition, a variety of research using integrated strategies designed to support students' in their construction of understanding this language are further explored. The strategies involve students in enacting the processes of science. These are more than hands-on investigations, more than inquiry, more than thinking, reasoning and argumentation, and more than reading or writing. The main strategies explored in this section combine one or more of these processes, but the focus here is on those strategies that emphasize science as inquiry and science as a process of thinking and reasoning through collaborative discourse, argumentation, and writing. Again, these strategies are not mutually exclusive as much of the pedagogy in the studies includes several of these scientific processes.

The language of science is complex. While relationships among and between terms make it conceptually challenging, there are additional characteristics of the language that also contribute to its complexity. It is "a language for the expert; one which makes explicit the textual and logical interconnections but leaves many local ambiguities" (Halliday, 1993a, p. 67). Seven characteristics of scientific English in particular were identified as contributing to interpretive difficulty: 1) interlocking definitions; 2) technical taxonomies; 3) special expressions; 4) lexical density; 5) syntactic ambiguity; 6) grammatical metaphor; and 7) semantic discontinuity (Halliday, 1993b, pp. 71-84 provides a more extensive explanation with examples). Interlocking definitions refer to the way in which terms are used to define each other. In technical taxonomies, terms derive meaning through their organization; they are related, "highly ordered constructions in which every term has a definite functional value" (p. 73). These constructions include term expansions, such as, describing the kinds, types, parts, or composition of a term. Special expressions are composed of a technical grammar where "it is the expression as a whole that gets to be defined" (p. 75), also a common mathematical characteristic. The content words, or lexical items, included in the writing influence the text's difficulty as does the number of content words, or the "lexical density" of a piece. Lexical density is key because it explains one difference between talking and writing. For example, "when the language is more planned and more formal, the lexical density is higher; and since writing is usually more planned than speech, written language tends to be somewhat denser than spoken language" (p. 76). When the intended meaning of a sentence is unclear, it is called syntactic ambiguity. For example, the kind of relationship might not be specified (cause or evidence) or the expression of the relationship might be unclear (i.e. what caused what). Syntactic ambiguity leads to another key point, as with

writers "we usually do not recognize the ambiguity until we try to re-word the passage in some other form" (p. 78), such as in translating for personal use or an audience. The grammatical metaphor is also crucial due to its strategic purpose.

In a grammatical metaphor, one grammatical class or structure is substituted for another. The same words can be used, but their place in the grammar changes. For example, in rewording for a younger audience the writer not only has to consider if there is a need to simplify the lexical items (words) chosen, but also perhaps the grammar that is used as it is sometimes not the words but "the grammar that is difficult for a child" (Halliday, 1993b, p. 79). With the grammatical metaphor, it is the wording, not the words that makes the piece difficult. In science writing, the process has become one of nominalization, where actions are written as things and verbs are used to represent what happened in between, often indicating a causal relation. The purpose of using technical terms in long nominal groups (words & grammar) "is to compress as much information as possible into a short space" (Martin, 1993, p. 168). The compactness confers efficiency and scientists could not do their job without it. This is in part due to "the function of language [in science] as technology in building up a scientific picture of the world. Technical language has evolved in order to classify, decompose and explain" (p. 202). Nominalization primarily facilitates one major function, that of classification.

To illustrate and structure the explanation of the grammatical metaphor, Halliday used a description akin to an extreme view employed by early embryologists, "ontogeny recapitulates phylogeny". The grammatical metaphor is developmental (ontogeny) as "children learn first to talk in clauses; it is only later – and only when they can already read and write with facility – that they are able to replace these clauses with nominal groups"

(1993b, p. 80). The phylogenic part of his description takes a bird's eye perspective in looking at history and the conditions in which scientific writing evolved. Scientific writing evolved in representing "a [new] kind of knowledge in which experiments were carried out" (p. 81). Although unconscious and unintentional, it evolved to use grammar in a particular way, to serve a particular purpose. The writing was based on "the principle of organizing information into a coherent form that suited the kind of argumentation that came to be accepted as 'scientific'" (p. 81). The purpose is to represent reality as what was found from what was done, representing reality as argument. To achieve this, he explains,

the discourse had to proceed step by step...[each idea] had to be presented in a way that would make its status in the argument clear. The most effective way to do this, in English grammar, is to construct the whole step as a single clause, with the two parts turned into nouns, one at the beginning and one at the end, and a verb in between saying how the second follows from the first. (p. 81)

The problem for students is this type of metaphor is "not just another way of saying the same thing," that is, not vocabulary substitution alone, but the metaphor functionally presents a "different view of the world" (p. 82). To understand the nominalization, "we have to reconstruct our mental image of the world so that it becomes a world made out of things, rather than the world of happening – events with things taking part in them – that we have become accustomed to" (p. 82). Halliday suggests this functionality may pose yet another problem for students, particularly if they are compelled to resist a view of reality as imposed on them by the language of science.

Lastly, semantic discontinuity occurs when readers are required to make leaps, for example, by inserting a logical relationship, forming a complex conclusion, or both. Halliday (1993b) claims this characteristic offers the most challenge pedagogically. However, if recognized by the teacher it could be harnessed and actually used as an

instructional strategy. To be effective, students must then have opportunities to read critically (Yore, Bisanz & Hand, 2003) to construct their own leap, or attempt to work out their leaps, explicitly. In summary, all seven characteristics are not arbitrary but have

evolved to meet the needs of scientific method, and of scientific argument and theory. They suit the expert; and by the same token they cause difficulty to the novice. In that respect, learning science is the same thing as learning the language of science. Students have to master these difficulties; but in doing so they are also mastering scientific concepts and principles. (1993b p. 84)

Together, Halliday and Martin (1993) contend that there is a need to "adopt a more constructivist approach" to our theories about "the language of science [which] is, by its nature, a language in which theories are constructed" (p. 8), occurring primarily through the grammar. For them, "the language is not passively reflecting some preexisting conceptual structure; on the contrary, it is actively engaged in bringing such structures into being" (p. 8). They explain this in that "all systematic thought" (p. 12) takes on meaning through language, which "construes" (p. 8) experience. In effect, "the language of science has reshaped our whole world view" (p. 10) by "being both a part of nature, physical, biological and social, and at the same time a metaphorical construction of the nature of which it is part. Scientific language has largely reconstrued experience" (p. 53). But this is the language of scientists; the language students are expected to learn. Bazerman (1988) argues the discursive nature of the experimental research report is a function of the culture in the scientific community. These products result from a need to attend to particular conventional demands, such as a need to anchor and develop arguments in an attempt to persuade the audience of the study's relevance to the community by being more useful or productive. Views from a sociocultural perspective add another dimension to the difficulties experienced in understanding the language of science in terms of belonging to different communities. Compared to most



students, teachers are already in a community that is more familiar with and comfortable using the language of science (Lemke, 1990).

In order to master science, one must be able to master the language (Lemke, 1990; Halliday & Martin, 1993). This mastery not only includes understanding of technical terms, but also the relationships and criteria for forming these (Martin, 1993). However, when there is a primary focus on the semantic relationships, classroom discourse can result in a distorted view of science. Lemke (1990) argues that conventional classroom talk misrepresents science in a variety of direct and indirect ways. The way typical speech patterns are used result in framing two dichotomous worlds, real and scientific, through language. "The language of classroom science sets up a persuasive and false opposition between a world of objective, authoritative, impersonal, humorless scientific fact and the ordinary, personal world of human uncertainties, judgments, values, and interests (Lemke, 1990, pp. 129-130). For Lemke, typical classroom talk removes the human element of science and reinforces the notion of scientific language as a reflection of objective truth. The language is presented as authoritative and difficult, constructs belonging to experts, and understood by only the most intelligent among us. For example, the role of decision making in determining what counts as evidence is not emphasized. Typical classroom dialogue tends to leave out historical changes in how particular "facts" have been perceived, misrepresenting science as an evolving series of progressive, successive advances. Scientific knowledge is typically conveyed as certain rather than fallible. For example, in one study of classroom instruction Moje (1995), scientific language was presented as unique, emphasized as *the* form to use to communicate accurately. After instruction, students reported that writing in science was not opinionated and involved restating facts in the writer's own words. In review of the study,

Rowell (1997) suggested that the focus on “scientific” language as the appropriate way to communicate might have interfered with students’ view of writing as a tool for learning, limiting the “generative function” of language (1997, p. 40).

The way the language of science is dealt with is also important for student learning. Helping students understand and communicate the language of science might be particularly difficult because it is often the language itself that is limiting. It is often a challenge for students to understand and remember novel terms. As discussed previously, a scientific term is not only a representation of an abstract idea in and of itself, but the definition likely consists of a link to other abstract ideas, which may also be represented by terms novel to the student (Halliday & Martin, 1993; Karplus, 1977). Notwithstanding these challenges, Lemke (1990) argues it is important for teachers to facilitate understanding of this terminology in such a manner that does not reinforce the idea that the language is inherently difficult, which effectively alienates many students from science. Students need to be able to talk science, that is, use the language of science in a variety of contexts because “communication...is always a social process” (Lemke, 1990, p. x). One approach is through collaborative group work where thoughts are externalized in speech, also known as verbal collaborative discourse.

Constructivism, across the various views, maintains that students learn through a process of social negotiation where students share their understandings, listen to peers’ explanations, and evaluate their own verbal expressions as well as those of their peers. Most educational researchers agree that students must be engaged in language use, as with von Glasersfeld (1993), “in general, language is learned in the course of interactions with other speakers, because speaking is a form of interacting” (p. 30). An interactive classroom helps

students develop language skills "and also provides them with opportunities to witness the use of words in the context of the experiences to which they refer" (von Glasersfeld, 1993, p. 30). Collaborative discourse is not conceptualized as an isolated strategy, but rather as an essential ingredient for most other methods. As Julyan and Duckworth (1996) explained, "constructing an understanding requires that students have opportunities to articulate their ideas, to test those ideas through experimentation and conversation, and to consider connections between the phenomena that they are examining and other aspects of their lives" (Julyan & Duckworth, 1996, p. 58).

Collaborative group work supports learning by "providing time for interaction with peers to answer student-generated questions, clarify understandings of specific science content, identify and resolve differences in understanding, raise new questions, design investigations, and solve problems...[and through these interactions] students can negotiate differences of opinion" (Tobin & Tippins, 1993, p. 11). As students discuss ideas, they have to make their implicit ideas explicit through speaking (Brown, 1988); hearing another's view allows an individual to reflect on their own position as well and consider it from another perspective, and in the process they are negotiating meaning (Roth & Roychoudhury, 1994). The teacher does not sit idly by, but has an important role "in establishing with the students a common language, that is, a language of carefully negotiated and coordinated meanings" (von Glasersfeld, 1996a, p. 311). Students need to be provided these negotiation experiences from which to make their own abstractions. Rather than consider answers as incorrect or misconceptions to be replaced, a student must come to realize how a new conception is "related to others that are already in the student's repertoire" (1996a, p. 312). Of the four primary language-based processes (talking, listening, reading, and writing), talking and

writing are two modes that are readily available for reflection on interpretations of reality to facilitate conceptual change (Barnes, 1976). Since writing is more permanent, it offers an additional advantage.

As evident in several descriptions above, collaborative discourse is one strategy that when embedded, can extend several other strategies. Lemke (1990) emphasized the importance of integration,

'talking science' does not simply mean talking *about* science [emphasis his]. It means doing science through the medium of language...[which] means observing, describing, comparing, classifying, analyzing, discussion, hypothesizing, theorizing, questioning, challenging, arguing, designing experiments, following procedures, judging, evaluating, deciding, concluding, generalizing, reporting, writing, lecturing, and teaching in and through the language of science. (p. ix)

Reading is also an important component in of "doing science." Even when meaning of technical terms are not well understood, Mallow (1991) argued that much could be gained from examining scientists' texts and their approaches to reading. For example, a scientist "slowly works through the article, making notes along the way. Unclear points are pondered over, references are looked up, numerical calculations are checked" (p. 329, 331). Students taught these strategies can transfer them to reading science textbooks. He also suggested that problems revealed in reading original research articles could be useful for learning. For example, science articles have a particular structure and audience, which often makes them difficult to comprehend. In addition, these articles do not accurately reflect the processes undertaken, as they are formal representations. The more formal presentation is a necessity, to efficiently convey information. In analyzing such texts, students can get some sense of "what is actually involved in original research and [in comparison] what the more popular descriptions of that research are obliged to leave out" (p. 327). Students also learn the

process that led to the experiment, how the present research builds on prior research, detailed methods, and the collaborative effort characteristic reflected in the number of coauthors.

However, revealing the problems in understanding components of the nature of science in the documents requires reflection and integration of other strategies, such as discussion, to help students successfully analyze the text critically.

Dixon-Krauss (1996) described the important tie between the personal and social realms involved in the "mediation model of literacy instruction" (Dixon-Krauss, 1996, p. 20). Expanding on one component in the model, she explains, "reflection focuses on analyzing whether the student is comprehending the text and on building the learner's self-knowledge through discussion. The discussion must include both the meaning derived by the student and how the student figured out this meaning. Having the student verbally reflect on how he used the strategies and figured out the meaning helps to build his conscious awareness of his own thinking" (Dixon-Krauss, 1996, p. 22).

There is some evidence that understanding language is facilitated by metacognition, thinking about one's own thought. In a study of the vocabulary behind metacognition, Astington and Olson (1990) compared linguistic abilities of students in different age groups. Students were asked to replace "say" and "think" verbs (for the actions of characters in twelve stories) with more specific terminology characteristic of science, such as imply, predict, interpret, infer, hypothesize, and conclude. They found high school students (grades 10 and 12) performed better than those in junior-high school (grades 6 and 8), demonstrating that metacognitive and metalinguistic skills were more developed in the older students. While it is not surprising that these skills improve with age, the authors suggested that knowing the language that describes thought might help students make important distinctions

among terms, clarify meaning, and communicate more effectively. Using metacognitive language may promote students' understanding in various knowledge domains, particularly in relation to difficult, more abstract, science concepts. Conversely, if students are not familiar with reflective vocabulary, then they may be at a disadvantage. These students could experience more problems when trying to improve their writing skills or in attempting to understand certain concepts targeted in lessons. Thus, it is not only the language of science that is important, but also the language of reflection.

While specific interventions to foster metacognitive skills offer some benefits, alone they are not likely sufficient to advance conceptual understanding. For example, Hogan (1999) found that eighth grade students who received a sociocognitive intervention targeting collaborative thinking and the metacognitive and regulation aspects of collaboration did improve their metacognitive knowledge and reasoning process explanations, yet they did not differ from control classes in either applying conceptual knowledge or in their use of these collaborative reasoning skills.

Considering the language of science is complex, and learning science involves learning the language, it is not surprising that researchers agree learning science is also complex, involving a "myriad of factors that contribute to proficiency" (Eylon & Linn, 1988, p. 290). To facilitate learning of science, researchers recommend multiple representations (Posner et al., 1992; Clement, 1977) of the content be used to address multiple learning modes of students (ex. aural, visual, and kinesthetic). Lazarowitz and Tamir (1994) argue that learning from laboratory experiences is "enhanced and supported by other strategies" (p. 111) such as visual media, computers, audio and individualized curriculum. In recognizing individualized factors affect learning (Eylon & Linn, 1988), educational researchers over the

past 30 years have responded and adopted a multidisciplinary approach to instruction, integrating a variety of modes of meaning making experiences that promote science literacy (Yore, Bisanz, & Hand, 2003; Holliday, Yore, & Alvermann, 1994). Multiple strategies highlighted in such reviews are those experiences that emphasize "authentic language uses and practices" (Yore, 2000, p. 107), which link hands-on to minds-on learning and provide opportunities for social negotiation through collaborative discourse, including verbal discussion, argumentation, critical reading, constructive writing, and inquiry investigations.

Understanding developed from these various experiences requires selection, explanation, and organization into a framework that makes sense to the learner (Osborne & Wittrock, 1983). Writing may serve as an important support mechanism to expand students' capabilities in navigating learning through these multiple modes of learning (audio, visual, and experiential), enhancing not only student learning of content, but also their capacity to utilize different modes of learning for future application and benefit (Eylon & Linn, 1988). Emig (1977) presented writing as "a unique mode of learning...[that] uniquely corresponds to certain powerful learning strategies" (p. 122). She explained that in the "reinforcing cycle involving hand, eye, and brain marks [writing as] a uniquely powerful multi-representational mode for learning" (p. 124-125). Writing generally proceeds slower than talking, which facilitates "the shuttling among past, present, and future. Writing, in other words, connects the three major tenses of our experience [doing/hand, depicting/eye, and representing/brain] to make meaning " (Emig, 1977, p. 127). As enticing as her argument is, there is little research that functionally isolates writing in a way that directly links it to learning (Ackerman, 1993; Applebee, 1984; Klein, 1999; Rivard, 1994; Rowell, 1997; Schumacher & Nash, 1991). As Rowell (1997) concluded,

at present, there is little empirical evidence to support the belief that writing *alone* serves as a mode of learning. Empirical studies which claim that meaning-making and/or knowledge restructuring results from writing activities have not isolated the writing from the other features of the classroom. This would suggest that, without appropriate contextual scaffolding, that is, interactions among students and teachers which are oriented towards development of ideas and processes in science, the promises of writing to learn are unlikely to be fulfilled. (p. 42)

One could argue that since education involves interaction and communication little learning could be conceptualized as resulting from any one strategy in isolation, albeit some research necessarily attempts to manipulate circumstances to control variables, revealing important influential factors. However, the lack of a consistent link to cognition led Klein (1999) to reorient the question from "*if* writing contributes to learning...[to] *when* writing contributes to learning, how does it do so? [emphases his]" (p. 206).

As others have provided more extensive reviews on writing to learn (Ackerman, 1993; Applebee, 1984; Klein, 1999; Rivard, 1994; Rowell, 1997; Yore, Bisanz & Hand, 2003), the research on writing to learn science here is not comprehensive, but instead highlights recent findings and those which informed the instructional designs for the studies enclosed. In addition, the implications such research has for the practicing teacher are explored, noting the important areas of focus for pedagogical implementation of writing as a tool for learning. Most of the research incorporating writing to learn activities assumes that writing fosters learning, as one mode, and have combined writing with other learning strategies in the classroom, particularly when such studies are based on constructivist learning theories. The studies then serve to show what learning is evident from the full process, including writing strategies, which often also serve as focal points of analysis.

What has become evident is that guidance, in the form of support through scaffolded experiences, is important for learning (Hallowell & Holland, 1998; Klein, 1999; Yore,



Bisanz, & Hand, 2003; Rowell, 1997; Patterson, 2001; Yore, 2000). Support from both teachers and peers is particularly important for more demanding tasks, such as when students are asked to create explanations (Fellows, 1994), solve problems that require complex reasoning (Eylon & Linn, 1988), and reveal their reasoning in writing laboratory reports (Keys, 1995). For writing to serve learning, Klein (1999) argued there is a need for "extensive cognitive strategy instruction...[which] "depends on creating a rich instructional environment" (p. 260). Providing "students with full writing strategy support" (p. 260) consists of clarifying strategy goals through guided prompts and discussion, and guiding students in practicing and monitoring their own progress in using the strategies.

One method of support involves combining practices in different disciplines, which educational systems have traditionally separated. Three primary disciplines, reading, writing, and science were integrated in a program developed for middle school students reading below their grade-level and as a result of these experiences students' improved their independent problems solving skills (Gaskins, et al., 1994). Specifically, students improved their abilities to identify components of a problem statement, select relevant readings, communicate conceptual understanding of simple machines in writing, and apply their learning in demonstration. These skills were measured in performance assessments; importantly, each improved skill was emphasized explicitly as part of the instructional program. Others recognize the benefits of integration in fostering active knowledge construction, inquiry, and problem solving learning; however, there is still a need for school based research to validate the effectiveness of integrating practices, and communicating findings of these various program specialties across research domains and out into the larger community (Glynn & Muth, 1994; Yore, Bisanz, & Hand, 2003; Eylon & Linn, 1988).

Importantly, an integrated approach can still be adopted even if there is not a formal integrated curriculum in place (Glynn & Muth, 1994).

Two learning strategies were integrated in a study by Rivard and Straw (2000), which stressed the importance of both verbal and written discourse. In the context of ecological problem solving activities, Rivard and Straw (2000) compared four groups of middle school students in Canada. Students in the comparison group individually completed traditional tasks such as, matching, filling in blanks, and defining; the "talk-only" group discussed with peers; the "writing-only" group individually wrote responses to problems; and students in the "talk-and-writing" group both discussed with peers and then individually wrote responses. On the first post-test, boys performed better than girls on measures of simple recall knowledge and integrated knowledge. On a second, delayed post-test, students in the "talk-and-writing" group performed better on simple and integrated knowledge measures than both control group students and student in the writing only group and better on integrated measures compared to the talk only group as well. Also, boys in the talk-and-writing groups performed better on simple recall than boys in the control group and talk only groups. Girls in the talk only group performed better on simple recall than girls who only wrote individually. While the study revealed some potential differences related to students' sex, these results emphasized the benefits of combining discussion and writing. Furthermore, in contrasting the two modes, Rivard and Straw (2000, p.583) explained, "oral discourse is divergent, highly flexible, and requires little effort of participants while they collectively explore ideas, but written discourse is convergent, more focused, and places greater cognitive demands on the writer" (p. 583).

Learning and thinking were evident in other studies that have combined writing with other visual modes such as reading and video-recordings of peers conducting experiments. In a study with university students, Tierney, Soter, O'Flahavan, and McGinley (1989) used a variety of 12 conditions to test the effectiveness of writing, reading, and questioning strategies alone and in combination. One main finding was that reading and writing in combination promoted thinking by contributing a wide range of revisions, idea additions, and better quality drafts compared to students who wrote without reading. Students with combined experiences generated new ideas and extended thinking in their text, and their debriefing comments indicated that they used writing as a generative process to access and organize information and elaborate on their argument. The researchers claimed that writing served to reveal ideas and resolve disputes, and reading provided a resource for examining alternative views and a stimulus for elaboration. However, the authors also recognized limitations in that they used short-term assessment measures for which there was no writing guidance provided or scaffolding through social interactions, so the environment was somewhat artificial compared to what might occur in the classroom.

In a study with high school physics students, Couzijn and Rijlaarsdam (2002) found that students who observed videos of their peers conducting experiments according to manual directions they had written themselves in response to pre-set goals, along with written feedback from those peers, improved their own revised explanations compared to an explanation only group. Students in an observation only group, who watched the videos but did not receive written feedback from peers, also had better revised explanations than the explanation only group. Interestingly, for peer readers conducting the experiments to score significantly higher on their manual explanations compared to the explanation only group,

they also needed to have provided written feedback. The findings suggested that students in those groups who were able to learn of potential "pitfalls" were better able to improve their explanations. However, only the peers who observed and wrote reviews were better able to identify more criteria for good explanations, the important elements necessary to convey concepts, principles, and the procedures in the experiment. The writing was conceptualized to serve a condensing function, solidifying students' ideas and facilitating subsequent retrieval from memory.

### Science as Inquiry and Argumentation

Attempts to emphasize literacy programs in the 1960's did not focus on developing independent, critical thinking, but were designed more "to mirror and thereby appreciate the way scientists themselves did their work" (DeBoer, 2000, p. 587). Since then, "if a single word had to be chosen to describe the goals of science educators...it would have to be *inquiry* [emphasis his]" (DeBoer, 1991, p. 206). Efforts to improve "skills in logical thinking and organization," and "building and communicating values concerning the nature of science" have become major goals for learning through laboratory work (Lazarowitz & Tamir, 1994, p. 106, 107). However, these efforts are not without problems.

One major problem with the hands-on movement during the early 1970's was the disconnect that existed between the activities and the content (Chiapetta & Koballa, 2002; Thier, 2001). While content was added in the 1980s, the activities still remained isolated from a guiding framework (Thier, 2001). Currently, in the National Science Education Standards, it is not only understanding of content that is important, but also understanding of science as inquiry, achieved through conducting inquiry processes. Inquiry is defined as "a set of interrelated processes by which scientists and students pose questions about the natural

world and investigate phenomena; in doing so, students acquire knowledge and develop a rich understanding of concepts, principles, models, and theories" (NRC, 1996, p. 214). There are two components of inquiry, reflected in different roles for the teacher and the student. In student-centered learning environments, teachers are expected to lead students through guided inquiry, providing discovery opportunities combined with direction, and encourage discourse that challenges students to make connections and justify their knowledge claims. Students are expected to conduct inquiry investigations, employ critical thinking and critical analyses of references and resources, formulate, justify and communicate their arguments, constructively assess those of others, and reflect on their own arguments and understandings. To secure the link to the standards, Chiapetta and Koballa (2002) recommend teaching science as inquiry, combining content with processes. Thier (2001) advocates guided inquiry in particular, where the teacher's role is to provide more structured and defined experiences that specifically align inquiry to curricular goals.

Tafoya, Sunal and Knecht (1980) described inquiry as a teaching process provided for students to investigate explanations to science questions that do not have an authoritarian answer. During this process, students actively investigate, with different materials in a variety of situations, form claims and perform empirical investigations to verify claims, and in doing so are expected to generate knowledge at their cognitive level. Making assumptions, observations, inferences, hypotheses, conducting tests, and revising their ideas are all part of the total inquiry process. These authors described four levels of inquiry investigations, confirmation, structured, guided, and open. For confirmation, a concept is presented to students, who know what is expected to happen and perform the activity for the purpose of verification. In structured inquiry, students are given the problem and the

procedures to follow, but work to discover relationships and generalizations. In guided inquiry, the teacher provides the problem, but the procedures to address the question are designed by the student. Finally, in open inquiry, the students design the problems as well as the methods used to address those problems.

The highest levels of inquiry are uncommon. Curriculum in the late 1970's did not emphasize higher-level inquiry opportunities, such as experimental design (Lazarowitz & Tamir, 1994). Results from more recent analyses indicate the problem persists today in European countries, and there is still little focus on emphasizing clear connections between laboratory activities and students' construction of science concepts (Tieberghien, Veillard, Le Marechal, Buty, & Millar, 2001). The more challenging activities are not observed often in classrooms as, "it is most unusual to find teachers who require students to generate questions and seek answers to them" (Tobin & Tippins, 1993, p. 11). When teachers perceive their curriculum is limited to certain topics suggested by local, state or national standards, possibly because they are assessed on proficiency tests, students are less likely to have free choice in their classroom pursuits. Perhaps scientists do not even practice the highest level, open inquiry, in its truest sense because they are constrained by the availability of material resources and often times reliant on monetary support through grants. For example, "beyond university much of the science being done is controlled by politics, since politics, whether wielded by governments or business interests, is the major factor controlling the dispersion of research funding for projects with short-term horizons" (Galbraith, Carss, Grice, Endean, & Warry, 1997, p. 466). For these reasons, the level of inquiry chosen for students' investigations in the research enclosed was that of guided inquiry.

In spite of the apparent disconnect between content and investigations, when assessment items match the instructional experience, there is some evidence that use of hands-on inquiry activities can positively influence students' performance on standardized achievement measures of scientific processes (Stohr-Hunt, 1996) as well as teacher designed assessments indicated by course grades (Tretter & Jones, 2003). Roth and Roychoudhury (1993) contend that process skills do not need to be taught separately as they found that both middle and secondary school students gradually developed fairly sophisticated inquiry skills over time in authentic classrooms where they did have influence and control over the design of their investigations. Posing their own questions related to phenomena experienced in their life, these students learned to select research problems, plan, design, and conduct investigations and advanced their data interpretation and analysis skills throughout the 14 month study. Students developed competencies in defining concepts, as the authors suggested, based on a need to have an effective means of communicating with one another during discussions related to planning their experiments and making observations. These results imply that opportunities for social negotiation throughout inquiry processes are essential.

Guidance has been specifically recommended in other studies. In a detailed analysis of conceptual growth in five college students, Wallace, Tsoi, Calkin and Darley (2003) found all students improved their understanding of purpose in the experimental process and most strengthened their knowledge of experimental design. Students with constructivist learning beliefs developed better conceptual frameworks compared to more traditional rote learners. The authors suggested that explicit instruction in constructivist learning strategies might further learning and that scaffolding at the beginning is important to compel students to

formulate challenging questions. They also suggested that guidance throughout the process would increase the potential to further their conceptual growth from inquiry approaches.

In addition to epistemological beliefs, several other factors are also thought to influence students' learning from inquiry related activities. For example, "students' learning styles, cognitive preferences, cognitive stages, and interests, needs, and attitudes have been shown to be important in laboratory learning" (Lazarowitz & Tamir, 1994, p. 121). Students' success in doing inquiry is thought to depend on other related cognitive abilities such as communication and prior exposure to the subject matter of the investigation (Germann, Aram, & Burke, 1996). Thus, Keselman (2003) suggested students need support during all stages of the inquiry process. Guidance for students is needed throughout the inquiry process, and additionally in helping students reflect on these activities. Such attention is important to provide students with metacognitive experiences. Explicit instruction in formulating predictions for sixth-grade students was found to contribute to improving students' inquiry learning, specifically in their ability to draw inferences. Again, teacher scaffolding of argument, particularly in justifying claims was recommended to further support students' inquiry learning (Keselman, 2003).

In one investigation without writing support, that is, guidance in the form of a template was not provided, Keys (1999b) found most middle school students' investigative reports consisted of compiled lists of facts and observations as opposed to interpretations relating observations to new claims or hypotheses. As part of a summer program covering water quality and zoo animal behavior, middle-schools students wrote reports both individually and collaboratively, respectively. Keys (1999b) found some evidence that students' texts served as a medium for conducting aspects of scientific inquiry such as



forming inferences from data, developing explanations, and composing new hypotheses.

While some students did connect claims and evidence in their writing and made a few meaningful inferences, a majority of the reports lacked evidence that new meanings had been generated from data, indicating students had problems directly relating their observations to new hypotheses or claims. As noted early, since there was no writing support, Keys suggested that explicit instructional guidance for writing, combined with opportunities to thoughtfully discuss meanings of the data might improve the quality of students' reports. Research into how students acquire evidence to back up their claims was also indicated.

For students taught traditionally and through an inquiry method using the learning cycle, Johnson and Lawson (1998) found reasoning ability was a better predictor of college level students' performance on final examinations than measures of prior knowledge. Reasoning ability was found to be a better predictor of achievement for students taught traditionally compared to those experiencing the inquiry approach. Since inquiry students improved their reasoning ability, scoring higher on a post-test measure compared to students taught traditionally, the researchers suggested this improvement diluted the predictive value of the reasoning pre-test for these students. Inquiry methods that focus on development of students' reasoning skills were clearly recommended.

Keys (1999a) argued the case that writing to learn strategies provide potential for students to reason and think critically about the meaning of data collected in laboratory work. Using their own language and style for writing laboratory reports was suggested to enhance students' personal knowledge development and contribute to positive attitudes toward the task (Lazarowitz & Tamir, 1994). The writing medium is "not only evidence of student learning, knowledge and engagement with scientific inquiry but also represents the means

through which students communicate with diverse readerships, their understanding of and commitment to this form of inquiry" (Hand, Prain, Lawrence, & Yore, 1999, p. 1033). In distinguishing from general inquiry, Chiappetta and Koballa (2002) explain "scientific inquiry centers upon natural phenomena and is an attempt to understand nature by explaining it and applying that knowledge. However, the knowledge has to be more than personally satisfying; it has to pass the scrutiny of other scientists through verification" (p. 90).

Attention to evaluativist criteria recognized in the interactive constructivist view are also recommended in the standards, as explanations "must be logically consistent...abide by the rules of evidence...be open to questions and possible modification" and based on scientific knowledge (NRC, 1996, p. 176). Instructional strategies that focus on developing students' proficiencies in using such criteria naturally incorporate elements of science as argumentation.

According to Kuhn (1993), one main challenge for students "is not one of acquiring correct experimentations strategies but of developing the ability to coordinate their existing theories with new evidence they generate" (p. 331). Indeed, the benefits from inquiry strategies are not without challenges as students experience difficulties related to several different skills. Students do not consistently design experiments to appropriately test hypotheses (de Jong & van Joolingen, 1998), they have trouble forming valid inferences (Keselman, 2003), and interpreting data for use as evidence (Kuhn, Garcia-Mila, Zohar, & Andersen, 1995). Students might only include a few claims supported with evidence and can have trouble positioning their claims under appropriate headings in written reports, even when directed by the teacher (Kelly & Chen, 1999). Students recognize they experience

some difficulty in constructing evidence in support of a claim (Hand, Prain, & Wallace, 2002).

To improve these skills, Kuhn (1993) suggests reasoning strategy training is insufficient in that students need to be engaged in the process of thinking, linking scientists' way of thinking, as argumentation, to their own thinking repertoire, which can be extended beyond the classroom. She argued, "if the goal is to enhance the quality of students' thinking it is essential to engage them in the practice of thinking" (p. 333). Argumentation can serve as a vehicle for students to experience the social realm of science, first hand, when "ideas are articulated, questioned, clarified, defended, elaborated, and indeed often arise in the first place" (p. 321). She recommends metacognitive training as a way to enhance the transfer of scientific thinking. Wellington and Osborne (2001) concur:

Put simply, it is because learning to think is learning to reason. Learning to reason requires the ability to use the ideas and language of science so that the student learns how to use new words in the appropriate manner, and to use familiar words with their accepted scientific meanings. ... Moreover, learning to reason in science requires the ability to construct arguments that link evidence and empirical data to ideas and theories. Practical work alone is insufficient to create a bridge between observation and the ideas of science. (p. 83)

Through argument, students individually construct knowledge from interactions with teachers and peers. Sharing ideas can mold and shape subsequent arguments. Through these social negotiations, students address their prior knowledge, face disequilibrium, and experience conceptual change (Driver et al., 1994). During conversations, students develop their scientific reasoning abilities by explaining theories and evaluating these theories based on presented evidence. Students also experience a need to support their claims with evidence. Learners are, in a sense, socialized or "enculturated" into a scientific mode of thinking (Driver et al., 1994; Kuhn, 1993; Roth, 1993). Adopting an interactivist

perspective, Rowell (1997) explained, "writing is a cognitive and a social act in which authors must go beyond individualistic expression for specific purposes such as building convincing arguments, effective explanations or insightful analyses" (p. 45). She argued that such extensions are necessary for writing to lead to knowledge transformation (Bereiter & Scardamalia, 1987).

Strategies that develop argumentation remain consistent with the discipline because "scientific knowledge is discursive" (Driver et al., 1994, p. 11). Duschl & Ellenbogen (2002) described argumentation as "a genre of discourse and an epistemological framework central to doing science" (p. 2). In their writings, scientists have created "a discourse that moves forward by logical and coherent steps, each building on what has gone before. And the initial context for this was the kind of argumentation that was called for by the experimental method in physical science" (Halliday, 1993a, p. 64). Some writing tasks used to develop argumentation skills might intend to mirror what scientists have done in their own genre. More importantly, students need more practice in

locating and interpreting information; in evaluating evidence and constructing arguments of their own; presenting their ideas in written and oral form; and defending their conclusions. Such work would recognise the central role of writing as a means of learning ideas, and not solely as a means of producing a record of work done. (Millar & Osborne, 1998, p. 2023-2024)

For several researchers "writing in science is conceptualized as a process that develops reasoning, inducts students in to the discourse of science, and promotes personal meaning in relation to scientific explanations" (Hand, Prain, Lawrence, & Yore, 1999, p. 1028). In examining what students were able to do with evidence in their writing, Kelly & Chen (1999) found that high school students who had constructed a musical instrument and then wrote a technical paper to explain the experiments they conducted with the instrument

adopted the scientific genre for their reports. However, this was only to a limited extent in that while they made several claims, essentially stacking facts, only some of these were supported with evidence. To improve the structure of their arguments, they suggested pedagogical adjustments were in order, such as making goals explicit and providing experience in which students could negotiate meanings of key terms. For example, a few terms relevant to argumentation such as claim, assertion, and consistency could be explored through discussion.

In another study examining undergraduate students' use of evidence in writing, Kelly and Takao (2002) found their products also adhered to conventions of scientific genres (Keys, 1999a). For example, students used multiple epistemic levels of argument, chains of reasoning, and pertinent evidence. Detailed textual analysis of two high quality papers in a companion study (Kelly & Bazerman, 2001) identified particular features in the writings, such as introducing and sustaining use of key conceptual terms, cohesion, and appropriate choice of epistemic level in various sections of the paper (i.e. generality high in introduction and conclusion). The authors suggested that sharing the criteria of the assessment model with students might serve as a heuristic to help students construct and evaluate their own arguments. They also recommended explicit genre and argument instruction as pedagogical strategies that might improve students' demonstration of scientific thinking.

Scaffolding in the form of report guidelines was provided in an extensive study with ninth-grade students (Keys, 1995). During a program integrating, hands-on investigations and verbal and written discourse during collaborative report writing, these students participated in discussions and wrote reports together in pairs. Lasting 4.5-months, students covered a range of topics including electricity, electromagnetic waves, chemical elements,

and bonding. Eleven distinct, traditionally recognized reasoning skills were identified in the written reports. Among these, some stood out as important from a constructivist view of learning. These skills included negotiation of conceptual meanings, comparing and contrasting models with objects, explaining and justifying predictions, and selecting appropriate resources. The social interaction experiences were interpreted to facilitate these skills.

Detailed analysis of the verbal discourse during laboratory and writing sessions of three student pairs revealed students relied on various negotiation roles. Students adopted five different roles during construction of their reports, serving as a soundboard, peer teacher, answer supplier, debater, and incorporator (Keys, 1996). Interestingly, the sounding board, peer teaching and incorporation were used for the more cognitively challenging tasks, such as when students experienced difficulty in explaining or applying concepts. Debate was used the least, and rarely by female pairs in the study. Domination was evident in one male student pair, leading Keys to highlight the importance of group composition not only for instructional purposes but also as an area for future research to look at student interactions in different group arrangements.

In a deeper analysis of six focus students' written reports in the study, Keys (1994) found students demonstrated several scientific literacy skills related to thinking and reasoning processes in their reports. Students made observations, constructed inferences, selected and processed relevant information, retrieved prior-knowledge, explained predictions, interpreted data, drew conclusions, formulated models, and compared and contrasted information. Analyses of the laboratory reports indicated that students improved their abilities to summarize relevant textbook information, compared and contrasted

information used to formulate explanations with greater clarity, and explained conclusions using observations. Conceptual growth was evident in analysis of concept maps from pre- and post interviews. And while this change could not be attributed solely to the scaffolded, collaborative report writing intervention, due primarily to the extended length of the study, Keys suggested that the expansion in content knowledge allowed for a more extensive base from which to draw for reasoning. Benefits from the collaborative experiences were emphasized in the previous companion study (Keys, 1996), and highlighted again as the social interactions were considered to serve an important role in the development of scientific understanding in addition to demonstrating competence in written products.

Research concerning inquiry, writing, and argumentation has not been confined to older students. For example, Duschl and Ellenbogen (2002) analyzed elementary students' discussions facilitated by a computer program called Knowledge Forum. These students worked in groups to analyze graphs of pulse data to determine a range for normal resting heart rate and identify the best representative graph(s). Students were then jigsawed into new discussion groups for electronic submissions of their findings. Thus, the submitting group was composed of students who had worked through the problem with different group members. While several laboratory groups had used mathematical calculations in formulating "decision rules" when determining ranges, they did not focus on these rules for decision-making in discussions, nor did they identify the best graphs. That is, students did not include the work they had done to make their decisions *as evidence for* their decisions. The researchers indicated that modifying directions to clarify goals and providing scaffold tools to encourage students to include evidence and make their reasoning explicit could enhance both their discussions as well as their arguments.

All studies demonstrated some success for students engaged in inquiry. While there was some downplay for a teacher who had experience aligning constructivist theory with pedagogical approaches to inquiry, by in large, most studies that combined writing, inquiry and argumentation recommended some form of explicit instruction, support through scaffolding, or both. Guided writing experiences may be one important form of support to help students attend to important rhetorical and content goals, which may free resources for attention to other factors in the composing process (Kellogg, 1987). This is the central thesis of the next section, which explores various models proposed to explain how writing might serve learning.

### Theoretical Models of Writing

This section introduces the classic theoretical models of writing to learn, highlighting the elements that are thought to encourage cognitive processing. Research into various components of these models are also explored, much of which compares characteristics of experts and novice writers. Lastly, limitations are acknowledged and implications from the literature are synthesized to emphasize particular factors teachers should consider when implementing strategies to promote learning science through writing.

An early model of writing conceptualized by Rohman (1965) remains commonly reported (Pressley, 1995; Zimmerman & Risemberg, 1997). Rohman (1965) proposed three stages of writing, 1) planning, 2) composing, and 3) revising. Further models refined the description of writing to a process of problem solving, during which the writer reasons through new material by revisiting the procedures of writing. Subsequent models have retained these basic processes, but moved away from conceptualizing the act of writing as moving sequentially through a series of stages (Flower & Hayes, 1981).



Flower and Hayes (1980) approached writing as a rhetorical problem that writers create and solve for themselves. They described two major units of the rhetorical problem, the rhetorical situation including the assignment the writer was given, which often defines the audience and second, a set of four main goals each writer individually creates. Two goals focus on the audience, one by the writer's intentions to influence the reader, and another in the voice that is developed to create a relationship with these readers, which can materialize in particular word choices and tone. The third main goal is meaning, which relates to how the writer organizes and expresses ideas. Levels of expression range from direct translation of ideas stored in memory to probing for relationships, contractions, and may include restructuring of knowledge on the subject. The fourth goal includes the actual production of the text, and decisions during this process may be based on the writer's prior image of the genre's conventions, but may also expand to include additional features such as providing examples or illustrating an image. In the process of producing text, the writer may "see" a fit for "previously unorganized ideas" (1980, p. 29).

In their study (Flower & Hayes, 1980), think aloud protocols were used to compare different processes used by expert and novice writers in completing an article describing their job for *Seventeen* magazine. College students who had sought assistance from the Communications Skills Center participated as novices and experts were either rhetors or writing teachers who had received a fellowship. Their main assertion was that experts and novices differ in the kind of problems they define to solve. One difference found was novices' tendency to focus on their topic, while experts spend more time throughout writing thinking about how they intended to influence the reader, and they argued that this planned attention to affect the audience was "one of the most powerful strategies we saw for

producing new ideas throughout the composing process" (Flower & Hayes, 1980, p. 27).

Compared to novices, experts also represented the problem in greater breadth and depth and developed their problems throughout the act of composing, in attending to all four main elements of the rhetorical problem.

Flower and Hayes developed a model to illustrate the basic cognitive processes, or the thinking skills, that writers use for composing. In developing their hypothesis, they stressed the creative processes that a writer engages in during text production in an attempt to theorize how writers learn as they are writing, an activity, which they argued is itself "a goal-directed thinking process" (1981, p. 366). The model (Figure 1) represents three main elements of influence over writing, 1) the environment, 2) the writer's long-term memory, and 3) the process of constructing the product. The environment consists of the "rhetorical problem" and situation, which include, the topic, audience, and requirements (exigency) of the task, the writer's own identified role in writing (often as a student), the evolving goals, and the emerging text. The second factor, long-term memory, includes the writer's knowledge of the topic, audience, and writing plans and can also include external resources. Interactions occur between components in the environment and long-term memory to influence the writing process. Three main components describe the processes of writing, planning, translating (composing), and reviewing (revising). These components are reflective of the stages proposed by Rohman's (1965) earlier model (Zimmerman & Risemberg, 1997); however, Flower and Hayes reject the linear stage theory to emphasize rather, a recursive nature of text evolution. Kellogg (1987) explained that while the end product reads in a linear order, the process of writing does not proceed in a sequential fashion by first collecting information, then planning, translating ideas into text, reviewing, and end in revising. Instead, the writer

can take different directions and use these writing processes in a variety of ways to produce the final product. Essentially, the double arrow could be inserted anywhere in the model.

Long-term Memory	↔	Writing Process		↔	Task Environment	
knowledge of:  topic audience writing plans		Planning	generating ideas		Rhetorical Problem	Topic
			organizing			Audience
			goal setting			Exigency
		Translating			↔	Evolving text produced
		Reviewing	evaluating			
revising						
	All Monitored					

Figure 1. Structure of the Writing Model Describing the Cognitive Process Theory (Flower & Hayes, 1981, p. 370).

All of the components in the writing process are monitored, although they recognized that individuals differ in the strategies they use to monitor, "writers appear to range from people who try to move to polished prose as quickly as possible to people who choose to plan the entire discourse in detail before writing a word" (Flower & Hayes, 1981, p. 374). The planning subsection describes mental acts such as accessing internal representations, which may consist of a network of ideas held in one word, or perceptions such as visual images. It also includes the sub-process of generating ideas, organizing these through groupings, category identification, and might also include forming new concepts. In setting goals during planning, the writer intends to form relationships, and once these are created, the goals may be further developed or revised by the writer anytime throughout composing. They expanded their description of planning (1984) as an incubation process where writers discover meanings for themselves, consisting of purposeful acts to get it right within. Expert's writing plans consist of "a pool of multimodal representation: notes, drafts, plans, goals, tests,

criteria, and imagined reader responses as well as all the imagistic, auditory, and schematic representations" (1984, p. 151). They contend that experienced writers use metacognitive strategies to examine their efforts and resolve goal conflicts. Such strategies are used, for example, to "sum up ideas and create gists...[and in doing so] they recognize the problem for what it is—a conceptual task, not a prose production task" (Flower & Hayes, 1984, p. 151).

Translating is the actual process of putting words on paper, taking ideas from the mind, transforming them into language, and externalizing them to text. Flower and Hayes (1981) suggested the decisions concerning what information to convey and how to communicate it may be complicated by circumstance, such as age and development addressed in the work of Carl Bereiter and Marlene Scardamalia (later described in more detail), or in the case where English is the writer's second language (Ambron, 1991). For example, Ambron (1991) recommended first using concept-mapping exercises prior to writing for ESL students, which reduces interference from competing resource demands in developing concepts first with a visual cue and then expressing these connections in writing. She explained students can be distracted while writing by "diverting too much time and attention in the search for the linguistically correct mode" (p. 115). Thus, some writers' translation process is constrained by consciousness required to formulate sentences and attend to grammar and spelling (Flower & Hayes, 1981).

To further illustrate the difficulties that can be experienced in the process of composing text and learning that may result, Flower and Hayes (1984) used an example of "shaping at the point of utterance" a hypothesis Klein (1999, p. 211) attributed to James Britton (1982). For teachers who invite discussion, it is not uncommon to hear a student begin to articulate understanding, only to pause mid-way to say, "I know it but I can't explain

it." This scenario is also familiar to writing teachers and teachers of other disciplines who use writing strategies. Flower & Hayes (1984) developed the Multiple Representation Thesis to recognize different forms of tacit knowledge reside within and the difficulties that arise in trying to relay these meanings through prose. As they explained, "the multiple representation thesis attempts to create a more operational definition of composing and planning that could include the process of understanding and meaning making" (p. 156). The thesis has two main points, first writers use a variety of symbolism to represent meanings for themselves, not just relying on text, and second, writers experience a series of constraints in the process of translation. A writer's "current meaning" is formulated in working memory and represents the present state, which may differ markedly from what ends up in print (p. 122). Such meanings can exist not only as words and concepts, but also as visual images, which are often easier to express in terms compared to other perceptual connotations from sounds or smells, for example. They explained,

as writers compose they create multiple internal and external representations of meaning. Some of these representations, such as an imagistic one, will be better at expressing certain kinds of meaning than prose would be, and some will be more difficult to translate into prose than others. Much of the work of writing is the creation and the translation of these alternative mental representations of meaning (1984, p. 122).

While thinking with various personal representations is useful for the writer, there may be a struggle to confine meanings to text, such as in the move from imagery or abstract networks. In writing a definition paper, they argued, "the critical writing skill they [students] must often master is not controlling style or genre, but translating a rich network or conceptual representation into a more expressible one" (p. 142).

The third writing process described, reviewing, includes both practices of evaluating and revising the text and can be a source for generating ideas (Kellogg, 1987). Reviewing can occur as a planned execution or may be triggered during evaluation of the text or the plan. While descriptions of the subsections have been ordered here, and arranged hierarchically in the model, Flower and Hayes (1981) further emphasized writing as a recursive process, during which the individual writer may address any element or subsection component at any time, that is, any one thinking "process can be embedded within any other" (1981, p. 366). Although revising, evaluating and generating ideas are particularly distinct in interrupting other processes. Revision can occur as the text is being composed and a change in the plan may occur after the text has been reviewed. In the process of regenerating goals, one component of the environment, the evolving text, functions as "the acid test of prose" (p. 385), to which new goals or plans represented in language must pass. They argued that setting, developing and regenerating goals represent "a powerful creative process" (p. 386).

Also using think-aloud protocols, Bereiter and Scardamalia (1987) contrasted novice and expert writers in terms of different approaches, knowledge-telling or knowledge-transforming. They found that novices, fourth grade students in this case, generally record or translate their ideas from memory into text, and in essence "tell" what they already know, without much planning or revising. Little value in terms of learning is thought to occur by this method. Knowledge telling is not considered reflective of a thoughtful approach, rather, to involve thinking writing must include attention to the rhetorical problems associated with producing the text and the understanding of the topic within the text (Scardamalia & Bereiter, 1981, as cited in Applebee, 1984). In contrast to novices, expert writers follow an approach represented in the "knowledge-transformation" model, and through purposeful, goal-directed

problem solving, or process of reflection, they access their ideas and generate content in response to rhetorical goals they had created. The process involves the writer's interactions between two hypothetical spaces, the content space and the discourse (or rhetorical) space. In the content space, the science student writer might deal with relevant facts, beliefs, data, and decisions concerning the topic (Keys, 2000; Klein, 1999). Activities in this space are in service to rhetorical goals, and might include recalling, relating, and evaluating content (Keys, 2000). The discourse space includes knowledge of the genre, such as text structure and format and rhetorical knowledge, such as planning. Activities include making particular linguistic choices and the actual construction of text. It is the shifting between these spaces that is thought to lead to a better understanding of the topic (Klein, 1999). For example, the writer might set a rhetorical goal to persuade readers and then develop a subgoal in the content space to compile evidence in support of the argument. On the other hand, if conflicting information is attended to, the writer may change one or more goals. Attention to rhetorical goals can lead to a transformation of content goals. For example, links can be discovered in the need to transition from one issue to the next or attention to ensure clarity for the audience may lead to clarification for the writer.

While the two problem solving models appear to differ somewhat in hypothetical locations concerning where transformations occur, key features that focus on the writer's purposeful decision making in coordinating a set of thinking processes and in generating higher-level and supporting sub goals are essentially the same (Klein, 1999). They both tend to lean toward the view of learning "in the act of writing," which influences goal modification or formulation of new goals that can also lead to new learning (Flower & Hayes, 1981, p. 366). Galbraith (1992) argued that in the problem solving models, discovery

appears to be more effective for the writer who is able to focus on higher-level rhetorical goals rather than the minutia of text structure. These characteristics may explain why expert writers appear to have an advantage over novices in transforming knowledge through writing according to those models. While rhetorical goals may serve to alter content, in the problem solving models the action is essentially explicit; however, in Galbraith's model described next, the action is essentially implicit (Galbraith, 1999; Klein, 1999).

Galbraith (1992) took a slightly different stance in conceptualizing writing as a process of discovery. Instead of focusing on thinking that occurs as a writer translates thoughts into language through awareness of goals, Galbraith emphasized, "the role writing has in constituting thought" (1999, p. 139). What is responsible for idea discovery in his model comes from an awareness of what one thinks, which emerges as the text is produced. The quote by E. M. Forster, "How can I know what I think until I see what I say?" summarizes his main position, although it is a familiar quote in writing-to-learn literature used to emphasize an interactive relationship between writing and metacognition (Applebee, 1984; Galbraith, 1992). For Galbraith, the quote illustrates his assertion that ideas are discovered as they are initially spelled out, the initial process is akin to a topic focused free writing experience. In his "knowledge-constituting model," (1999, p. 144) he focuses more on how cyclic translations of text production result in generation of content. In his model, problem solving has its place, but more is reserved for revision.

Galbraith (1992) argues that a planned strategy model assumes that the writer has an organized conceptual structure that can be translated effectively, which results in a conflict for the writer, "between finding out what to say and saying it in an appropriate way" (p. 49). The difficulty may have detrimental effects on motivation, resulting in procrastination or



complete blocks. To avoid such problems, he advocates taking an unplanned approach described by Elbow (1973) in which all thoughts are spelled out initially instead of planning first. Main ideas are then summed up in a continual process, writing thoughts and summarizing what was written, still spontaneously, but subsequent expression relies on "the assertion extracted from the first draft" (1992, p. 49). This process is intended to clarify thoughts as goals emerge over several drafts. From this unstructured exploration of ideas, the writer discovers ideas and engages in a process of construction. Expression and organization are ignored during re-writes, reserved for the final draft when goals are then used as a guide to text structure. In this form, the writer focuses on thoughts, not the reader, until the end.

To test his position, forty-eight undergraduates were selected, based on the results of a self-monitoring questionnaire, which identified them as either high self-monitors (socially influenced) or low self-monitors (individually influenced). High self-monitors reported their behavior was influenced by external cues from others and thus were assumed to write rhetorically (goal directed), while low self-monitors reported that they act in response to their own feelings and intentions, without responding to external influence, and were assumed to write dispositionally (expressing ideas). Initially, students rated how much they felt they knew about a topic of their choice prior to writing. They were then asked to list all their ideas about the topic in ten minutes and rate the importance of each idea. Approximately half of these were then instructed to write an essay about the topic, while the other half were instructed to make notes in preparation for writing an essay. After writing, students then repeated the step of listing and rating ideas. Finally, the original list was returned and students rated the degree of correspondence between ideas on the two lists. The essay group

was expected to spell out more ideas in their translation, while the note group was expected to have more attention available for planning.

One caveat is in order before introducing results as the interpretation was complicated by his attempt to measure idea change. While the pre-measure was removed during text production, he had students list all of their ideas on the topic; essentially, all students had a chance to "spell out" their ideas initially in brief notes, which appears to complicate the very target of his study. Galbraith cautioned that his findings better represent hypotheses for further testing due to limitations in the design such as in the use of self-reports of knowledge and the measurements' capacity to fully capture writers' attributes. Nevertheless, Galbraith related results in this study to previous research from his thesis to provide support. One interesting finding overall was that low self-monitors who wrote essays (assumed dispositionally focused and unplanned writing) and high self-monitors who wrote notes (assumed rhetorically focused and planned writing) both produced more new ideas than the other group combinations. The interaction indicated that students were able to construct new frameworks, but through apparently different approaches.

In another study with college students testing the effectiveness of two planning strategies, Kellogg (1987) compared persuasive letters written under two conditions. The groups included writers who used outlines to produce rough drafts, which were then revised for expression, or writers who began immediate pursuit of the final version, attending to expression during the act of composing. Students who did not use outlines also produced either rough drafts for revision or directly pursued final drafts. Kellogg argued that while both outlining and rough draft construction benefit the writing process as a whole, he found the task of outlining had a greater impact on improving final drafts than did preparation of a

rough draft. He explained that production of a rough draft might make it more difficult for the writer to abandon the ideas they constructed in words and less likely to completely rework some of the other phases, such as recollecting information, replanning, and retranslating. He found outliners wrote more words and had better quality letters as indicated by idea development and effectiveness. He suggested that outlining might function to reduce cognitive demands, freeing time and attention to invest in translation during writing rather than planning and reviewing. In a companion study of surveyed academic writers he found that outlining positively correlated with self-reported productivity; however choice of draft strategies, (rough free write, or direct initial pursuit of the intended polished end) did not appear to influence performance.

Findings from a recent study (Keys, 2000) indicated that eighth grade students employ at least two different strategies during construction of laboratory reports, backward searching to attend to rhetorical goal planning and the shifting between content and discourse spaces (Bereiter & Scardamalia, 1987; Flower & Hayes, 1981; Klein, 1999). In this study, Keys combined think aloud protocols and textual analyses. Students wrote individually and guidance was provided through rhetorical goals from the teacher and through a laboratory-writing template. The teacher encouraged students to generate content goals, verbalize their reasoning, and reflect on their experiences collecting local data concerning the topic of erosion. To illustrate the movement between the discourse and content space, Keys found that students most often began composing, and then realized a need to generate content, for which they returned to the content space to generate hypotheses, evidence, meanings, or claims before proceeding. For example, the generation of a hypothesis on the factors that affect erosion in direct response to recording trench depth measurements was found from the

analyses. She explained that the interaction between spaces stimulated reasoning and thus has the potential to influence learning. Interestingly, the think aloud protocol did not result in evidence that discourse interactions were necessary to generate meanings for all students. Rhetorical goals were more important for two students in particular who generated content in response to the main goals provided and then generated their own subgoals for organization. Keys recognized the lack of detection could have resulted from limitations in timing, for example, which might not have caught discussions taking place during the outdoor work or in unarticulated thinking.

In addition to rhetorical knowledge of grammar, and a wide vocabulary, Zimmerman and Risemberg (1997) argued that competent writers also differ from novices in practicing self-regulation. Self-regulation stems from a locus of control; writers determine when they begin (self-initiated), how long they write (self-sustained) and what they will do during the writing (self-planned). Monitoring occurs in a feedback loop that is personally controlled by the writer, in much the same way that the writer is thought move recursively through writing processes in the problem solving models. Strategy interventions, focusing on self-regulation techniques, may help poor quality writers improve their writing performance. Such strategies direct attention to controlling the environment, which includes accessing writing resources, and promote self-monitoring of their own strategies, practices, and writing behaviors. Zimmerman and Risemberg (1997) reported results from Risemberg's earlier dissertation work (1993) during which compare and contrast essays were assigned to undergraduate students. The time students spent accessing help documents, essay models and a format guide, was recorded. He found that both reading ability and guide accessing predicted the quality of the essays. The effect of access disappeared after students were taught a strategy

using a graphic organizer, as these students then accessed the help documents less than students who were not taught the strategy. For students taught the strategy, the organization of notes predicted the quality of essays. While both strategies appeared to benefit students, highlighting the importance of rhetorical support presumably through the planning process, providing direct instruction might interfere with students' self-directed initiatives.

In synthesizing results from six studies, Hillocks (1986) suggested that students' self evaluation or peer reviewing were more important for improving writing than direct instruction, of grammar for example, when their reviews were guided with specific criteria. Internalizing such evaluation criteria could serve as standards to apply to their own writing (Zimmerman & Risemberg, 1997). Undergraduate students provided with a form to evaluate their own writing goals and text identified more problems than when they did not use the form (Beach & Eaton, 1984). Zimmerman and Risemberg also suggested that there is a positive relationship between writers' use of regulation techniques and self-efficacy. However, they noted that more research is necessary to fully illuminate motivational influences related to writing, particularly addressing how certain methods might help students become self regulators, navigating through complex interrelated processes both in writing and self monitoring.

Also in a study at the college level, this time with women writing comparative essays, Ferrari, Bouffard and Rainville (1998) compared texts produced by strong writers to those of weaker writers, as classified by their teachers. Compared to novices, they found that strong writers produced longer, better quality texts, used more contrasted ideas, and expressed these ideas through comparative structure. Stronger writers also knew more about important elements to include in comparative text. The basic discourse knowledge of organization

(introduction, body, and conclusion) was applied similarly between groups, and they also made about the same number of improvements to their texts. However, poor writers introduced more detrimental changes to their texts, in spelling, grammar and punctuation. In comparing the similarities and differences between the groups, the authors suggested that weak writers' deficiencies in linguistic knowledge contributed more to their poorer quality products than did a lack of self-monitoring.

#### Limitations and Pedagogical Considerations

Findings from these various studies examining the factors involved in the processes of writing that may affect writing quality and may lead to learning are likely influenced by a variety of personal factors. In any of the models described, authors recognized that the order in which each process is undertaken is highly individualized and often dependent on the task itself, as well as the writer's interpretation of the task and their role in writing (Applebee, 1984). The various paths writers take to accomplish their tasks, and the success they experience both during the process and as a result of writing, can be influenced by a variety of factors. Some factors that may interact include the writer's, personality, perceptions, previous content and rhetorical knowledge, prior experience, prior success, strategy training, self-regulation, self-efficacy, present writing goals, motivation to perform well on the present task, current experiences during the act of writing, and current perceptions of success. None of these factors are thought to work in isolation (Applebee, 1984; Flower & Hayes, 1981; Zimmerman & Risemberg, 1997), but as some of the studies above have shown, research necessarily manipulates a few at a time to better understand the influence each may have on learning. While findings from a few studies indicate that students have particular methods of approaching writing tasks, what remains in question is whether or not they benefit from

instructional approaches that utilize strategies different to what they have become accustomed.

While the theoretical models do provide general insight into the processes involved in text generation and revision, which may be useful for writing to serve learning, each one is limited in ability to completely explain the processes or how writing leads to learning (Klein, 1999). None of these models is conceived to be the "set" model and as with the discipline of science itself, all are open to re-conceptualization. The studies illustrate how asking different kinds of questions about writing and learning from distinct perspectives through a variety of research designs likely contribute to the inconsistent pattern in findings that attempt to address knowledge change through writing (Schumacher & Nash, 1991; Klein, 1999). Looking at writing to learn from a cognitive perspective is criticized for neglecting the broader social and cultural influences. For example, Greene and Ackerman (1995) argued that the early model proposed by Flower and Hayes located contextual elements "on the periphery of activity" (p. 387).

Applying social constructivist theory attempts to change what it means to write, shifting from conceptualizing writing as an individual act to an "event" that is socially constructed, not simply situated in a social environment (Newell, in press). From this view, what is defined as rhetorical is considered through a wider lens to include "the means and circumstances through which readers and writers represent and negotiate texts, tasks, and social contexts" (Greene & Ackerman, 1995, p. 383). Such a perspective takes into account how the use of language serves to form the relationship between writers and their readers. To better illustrate the role of text in "mediating the respective purposes of the writer and reader" Nystrand proposed an interactive model of written communication in which the

product is situated between the reader and the writer (1989, p. 76). In this model, "texts have meaning not to the extent that they represent the writer's purpose but rather to the extent that their potential for meaning is realized by the reader" (p. 76). From the interactive perspective, meaning is not construed by "the writer alone but in terms of interaction between writer and reader purpose, [that is,] not in terms of the text's *semantic content* but rather in terms of its *semantic potential* [emphasis his]" (p. 76). Greene and Ackerman (1995) argued that writers' positions in texts are influenced by 1) authority, through expertise or conventions of a community, 2) writers' purposes within a social context, and 3) the topic or task. With a similar critical analysis of the cognitive models, Giroux and McLaren (1992) related the argument to the social perspectives of discourse and language production, "as a socially organized and culturally produced human practice, language never acts on its own but only in conjunction with readers, their social locations, their histories, and their subjective needs and desires" (p. 15-16). While recognizing evidence exists concerning social influences on writing, Klein (1999) contended that the links to learning remain obscure and more research is needed to further describe and establish these roles.

Nevertheless, these broader social influences can, or rather should be considered in instructional design of the activities, and in choosing topics and tasks as part of the supportive strategies for both writing and learning in science (Galbraith & Rijlaarsdam, 1999; Newell, in press; Yore, Bisanz, & Hand, 2003). As with Rowell's assertion, "without appropriate contextual scaffolding, that is, interactions among students and teachers which are oriented towards development of ideas and processes in science, the promises of writing to learn are unlikely to be fulfilled" (1997, p. 42). Newell (in press) argued that teachers need to be informed by both constructivist and process-oriented approaches. Taken together,



these more appropriately address the various ways in which different disciplines conceptualize knowledge and structure writing, that is, "what it means to know and do." For example, both are necessary to explore how knowledge is constructed in and/or represented by specialized genres and in the conventions particular to disciplines, such as in science for example (Newell, in press). Galbraith and Rijlaarsdam (1999) also support combining both cognitive and social approaches for teaching writing, as even though cognitive factors are emphasized in research, findings are often suggestive of influence from social variables, such as length of opportunity for discussion, of find effects in terms of motivation and influence from peer reviewing. Studies reviewed here also demonstrate this. Several researchers contend that process approaches that focus on reflective practices in writing and active construction are consistent with constructivist learning theories, for example the knowledge transforming model as opposed to knowledge telling, (Keys, 1999a; Hand, Prain, Lawrence, & Yore, 1999). In enacting such programs and practices, Newell (in press) argues that it is important for students to feel valued as participants in actively contributing to the social constructive process. Examples from qualitative studies suggest students are empowered and perceive personal benefit in experiencing methods that promote dialogue and embed writing activities in collaborative, interactive social contexts.

Social interactions appeared to be paramount in a study by Chinn and Hilgers (2000) who found university science students perceived they learned more content and improved their own writing effectiveness when provided collaborative and authentic writing experiences. Instructors that provided collaborative experiences were rated highest on student evaluations. Described as collaborators, these instructors used a variety of techniques to foster a community environment as part of their instruction. For example, realistic writing

activities with explicit instructions were used, which had potential for professional application. Feedback was provided through peer reviewing, instructor feedback, or both and writing was presented as tool for learning about content, literature and effective communication.

Feedback may promote a dialogue that contributes positively to students' confidence (Hanrahan, 1999). In a study with eighth-grade science students who had scored below average on a basic literacy test, journal writings were assigned throughout the year. Hanrahan provided affirming feedback through written comments that validated students' thoughts, views, and feelings about science experiences, which they were encouraged to express in their entries. In writing journals, students practiced their literacy skills; however, the combination of affirmational feedback acted as a dialogue to promote positive self-concepts, which she argued was even more important for motivating students. While the dialogue was primarily a two-way interaction, she claimed such practices changed the nature of power relationships between the students and their teacher, creating a more authentic learning environment. Hanrahan did not focus on measuring literacy skills; however, Ambron (1987) argued that these types of tasks stimulate critical thinking even when they do not directly result in improving the quality of writing on subsequent tasks. She claimed that journal writing at the college level "helped students clarify their thoughts about course content" (p. 264) but she did not find that this led to significant improvements in essay or laboratory report writing. How then might writing act to stimulate thinking?

Writing provides a medium for argument by offering a permanent record of thought for review and reflection. The permanency enables the writer to evaluate evidence used to argue a claim, ideas can be revisited, and thoughts revised (Applebee, 1984). As an active

process requiring clarity, writing encourages the writer to attend to meaning and coherence, facilitates self-examination of experiences, ideas and assumptions, and provides a medium for metacognitive experiences. Metaconceptual awareness is considered fundamental to learning, as Kuhn explained,

what children or adults need to be able to do is to distance themselves from their own beliefs to a sufficient degree to be able to evaluate them, as objects of cognition. In other words, they must have the capacity and the disposition to think about their own thought. (1993, p. 331)

While it cannot be guaranteed that writers will partake in all of the processes offered by the written word, the potential of writing to stimulate thought and reflection has been revealed in several classroom studies that also capitalize on social interactions for constructive experiences.

Fellows (1994) found that when middle school students compared their writings on matter and molecules, writing and reflecting individually and in groups, they added new concepts and theories, improved organization, and expressed understanding in a more logical manner, closer to the scientific explanation. These students viewed writing as a tool for thinking, which led Fellows to suggest that writing provided a medium for metacognition, and the combination of reflective feedback supported students' conceptual change. Similar results have been found with fifth-grade students who explained their reasoning behind idea change in writing (Mason, 1998). Mason found most students' post-discussion writings were reflective, in which they described changing their initial conceptions (those they had prior to discussion). Interviewed students attributed these changes, many closer to scientific explanations, to the collaborative opportunities for reasoning they experienced during discussions.

After experiencing multiple writing tasks, Prain and Hand (1999) found high school students "were more aware of how to approach their own learning, and also developed the ability to judge whether their writing efforts were 'on track,' especially when they had opportunities to get feedback from other students about the clarity of their representations of concepts" (p. 159). The social interactions contributed to their cognitive development in serving as a public arena to test their ideas and understandings. These students also developed rhetorical knowledge, in recognizing the requirements involved in their writing tasks, and interestingly they attributed this understanding to developing higher-level thinking skills. Moreover, students viewed science more positively as a result of experiencing various writing tasks. When asked to comment on the value of particular writing tasks, students clearly articulate metacognitive thinking and often link these experiences to writing (Hand, Prain, & Wallace, 2002). From a broader cultural and curricular perspective, writing activities that encourage self-regulation and metacognition by asking students to reflect on learning processes are generally considered to have positive effects on learning (Russell, 1991; Newell, in press). Students' knowledge of metacognitive skills is considered important for writing to contribute to learning in science (Rivard, 1994). While the literature has not distinguished the roles of writing, metaconceptual awareness, and collaborative experiences (Klein, 1999), the research suggests that in combination, such strategies interact in a way that provide benefits that may contribute to learning. The motivational potential of such practices adds a further dimension to examine, as it might be interesting to determine what kinds of tasks elicit positive student responses similar to those reported by Prain and Hand (1999) and whether any demands or characteristics of such tasks in particular are responsible for these views.

Few studies have been conducted focusing on the nature of the task and its influence on learning (Klein, 1999), however the exigency, or the demands of the task are thought to influence the level of difficulty writers experience in completing the task (Flower & Hayes, 1984). Different types of tasks have different requirements, which may affect conceptual learning targeted in task. Drawing on general conclusions from research concerning the effects of questioning on understanding, Applebee (1984) noted, "any manipulation (or elaboration) of material being studied tends to improve later recall, but the type of improvement is closely tied to the type of manipulation" (p. 584). Extending these general findings to writing and learning, he suggested that for certain concepts,

we might expect that the more a writer must manipulate new material in the process of writing about it, the better that writer will come to understand that material. This should be particularly true if understanding is measured by ability to apply new concepts in new situations, rather than to recognize material that has been previously presented. (p. 586)

For example, Newell (in press) described different processes evoked by three writing types, restricted, summary, and analytic. Restricted writing essentially involves little composition, such as in responding to questions. This type of task is useful for preparation and review to facilitate retrieval from short-term memory. Such learning might be limited in its tentativeness, but would be useful in subsequent application to more difficult or challenging tasks. Summary writing is useful for review and preparation as well, and additionally this task tends to include big ideas and necessitates planning for how content will be combined to work together in a piece. Summaries may promote general recall of facts, but again might be retained for only a short period. In analytic writing, the writer addresses the how and why questions in explaining, persuading, or arguing a case, which requires attention to language selection. Having to examine relationships in the process of writing is thought to require

more complex thinking and reasoning resources. Thus, understanding of relationships might be better developed from writing essays focusing on applying ideas to new situations (Applebee, 1984). A study comparing the effects of note-taking, question responses, and analytic essays showed an effect for students writing essays over the other groups, but only in gains of passage specific content not in application measures (Newell, 1984). Several researchers (Newell, in press; Langer & Applebee, 1987; Tierney, Soter, O'Flahavan, and McGinley, 1989) have recognized these different writing types contribute to the "confusing pattern" of findings, as Schumaker and Nash noted, "different kinds of writing tasks eventuate in different kinds of cognitive operations thus resulting in different kinds of learning" (1991, p. 69).

Considering the topic of focus in such essay tasks is important as it may influence the level of thinking stimulated or degree of response elicited. Findings from the study conducted by Tierney Soter, O'Flahavan, and McGinley (1989) suggested persuasive tasks promote critical thinking. However, because they found significant differences in students who wrote about xenotransplantation more often than in comparisons of students' writings concerning gender discrimination, their findings could have been influenced by the topics. For example, a particular issue that evokes stronger opinions may influence the level of thinking students engage in. Students' background knowledge or familiarity with a topic might also affect the level of engagement. Strategy interactions, such as the timing of the tasks, may also be important as their results suggested writing supports more evaluative thinking when it precedes rather than follows reading.

Another element of the writing task, audience, encourages the writer to manipulate language, which may affect the quality of learning. Results from interviewed students

indicate that the audience may be a key element to promote thinking. As students recognize a need to change their language, simplifying terminology for their peers, they concurrently report this need to translate technical terms and science concepts requires more thinking on their part (Hand, Prain, & Wallace, 2002). Journalistic writing style requires students to simplify their language for the public. College science students assigned this genre had to "discuss complex issues as simply and as precisely as possible using a minimum of specialized vocabulary" (Halloway & Holland, 1998, p. 29). In doing so, even though some students recognized the difficulty in translating to effectively communicate with their audience, a large majority of students expressed positive views of the task. While students were provided with instruction in the genre, and presumably had access to relevant models in the newspaper, many still felt that they needed more strategy support to be successful in their writing. Considering that expert writers are more aware of their audience than novices, recognizing readers' background knowledge and linguistic level and addressing these as part of the rhetorical problem (Bereiter & Scardamalia, 1987), tasks which by nature direct attention to focus on the readership may stimulate adoption of experts' approaches. In addressing the needs of an audience, Rubin (1984) argues that writers both "analyze and invent [dimensions of their readers] but in varying ratios depending on the writing task" (p. 215). Since the writer's attention is also required to deal with content knowledge in the piece, Applebee (1984) cautions that topical understanding should not be sacrificed in instruction that places too much emphasis on attending to the needs of the audience.

However, a well-defined audience may help the writer conceptualize the goals of the writing task and improve motivation to write by providing a sense of direction for the writer. Zimmerman and Risemberg (1997) explained that pursuing a goal to communicate

effectively with an audience influences success, as “writers must be aware of readers’ expectations and must be willing to devote the personal time and effort necessary to revise text drafts until they communicate effectively” (p. 76). Fahnestock and Secor (1988) contend writers need to match the argument to their audience, taking into account what kind of impact their message might have on the values and actions of their readers. Rowell (1997) suggested that it might be useful for students to write to several audiences with various kinds of writing tasks; although, simply increasing the number of writing tasks will not necessarily result in more or better quality learning (Bangert-Drowns, Hurley, & Wilkinson, 2004).

Beginning to address this issue in reporting two studies at the high school level, Hand, Prain, and Wallace (2002) found a significant difference in conceptual measures between groups of students completing traditional and non-traditional writing tasks. In one study, students wrote about light using non-traditional writing tasks, which included using the Science Writing Heuristic during five laboratories, and then a summary task integrating their laboratory experiences to explain reflection and refraction in a letter to students of the same age in a different school. These non-traditional writers performed better on a higher-level test question compared to students who copied lecture notes and were directed by the teacher during laboratory activities. In the second study, non-traditional writers wrote only once, constructing an editorial letter to the newspaper arguing for and against the use of genetic filters. These writers used significantly more higher order concepts in their responses to an analogy test question when compared to traditional writers, although the groups did not differ on overall test scores. Interviewed students pointed to the demands of the task as helping to improve their understanding. The task goal of attending to their audience required translating language, which they explained contributed to their own learning of concepts



targeted in the task. Although they cautioned readers against premature generalization due to small sample sizes and limited subject matter areas in the investigations (genetics and light), some learning was evident. Comparison of the two studies indicated that students might need to write more than once before significant differences can be determined on conceptual test measures, suggesting benefits may be cumulative.

To detect such benefits, one point the authors made is particularly relevant to assessments of writing targeting conceptual understanding. As with Applebee's previously presented argument, if we can assume that the degree of manipulation impacts students learning, "there would appear to be little value in promoting learning strategies that require students to think more deeply if test questions do not measure this level of thinking" (Hand, Prain, and Wallace, 2002, p. 33). Approaches most effective in promoting conceptual change are those that help students make links between related ideas, identify misconceptions, and provide opportunities for in-depth coverage (Eylon & Linn, 1988). Exploring a topic in-depth allows students to make their own links and connections between ideas and educators adopting writing-to-learn strategies contend that writing tasks can provide such opportunities. Problem-solving research, for example, maintains that writing promotes learning by providing a medium of opportunity in which ideas can be fostered, links can be formed, and attention can be given to the consistency of an argument (Applebee, 1984). However, these promises are not always realized as writing tasks in high school classrooms typically consists of unchallenging, brief activities, such as short answer responses and note taking (Langer & Applebee, 1987) and writing is used primarily as a means to test knowledge rather than serving as a tool to transform it (Rowell, 1997; Rivard, 1994). This also appears to be the case internationally, in Australia, "very little writing is used to extend or consolidate

knowledge...For the most part field is explored orally; what writing there is is restricted to definitions, short answer questions, [and] fill in the blank exercises" (Martin, 1993, p. 201). And in England and Wales, where "too much of the summative assessment of students is still based on factual recall which bears little relationship to the sorts of situations beyond the classroom, where students may need to apply their scientific knowledge and skill" (Millar & Osborne, 1998, p. 2004). Rivard (1994) concluded from his review that writing leads to learning when goals focus on "deep conceptual understandings" rather than regurgitation (p. 978). When strategies are used to deepen understanding of topics, intending to help students construct links between concepts and ideas, students need to be assessed accordingly. There is a need for alignment of goals, instructional strategies, tasks, and assessments (Hallowell & Holland, 1998; Henriques, 1997; Rivard, 1994; Millar & Osborne, 1998; NRC, 1996). Without alignment, it is possible that distinctions in the quality of learning resulting from writing tasks may remain somewhat elusive (Newell, in press; Newell & Winograd, 1995; Langer & Applebee, 1987).

Additionally, embedding cognitively challenging questioning in instruction and assessment provides more opportunities for students to practice critical thinking and improve their understanding. The type of questions used in assessments are important as Crooks (1988) explained, "the use of higher level questions in evaluation enhances learning, retention, transfer, interest, and development of learning skills" (p. 442). Timing of the assessment might also be important, as Andre (1990) found embedding application questions in text improved student learning on application items compared to students in the fact receiving group, not on an immediate post-test, but rather after both a one and two day delay. While higher-level questions are thought to facilitate longer retention, students may need more

cognitive processing time. A series of related writing tasks increases the amount of time for students to develop and strengthen links between concepts. Hand, Prain, and Wallace (2002) suggested that in implementing multiple writing tasks, there should be some variety so that students not only have additional time to develop connections through extended writing experiences, but also experience multiplicity in extended coverage so that such activities are not perceived as needlessly repetitious. Several writing experiences also provide teachers with more opportunities to scaffold writing processes and help students develop their self-monitoring and evaluation skills. Extended time is also considered an important factor for students in sharpening such monitoring skills (Bangert-Drowns, Hurley, & Wilkinson, 2004). Longer intervals are crucial when considering that abstract reasoning, higher-order thinking, and writing process skills are all thought to evolve and develop over time.

This has important implications related to expectations and curricular design. In the short-term, success in terms of higher-order cognitive processing will not likely be realized and benefits remain undetected from one-shot writing interventions. More broadly, pedagogical decision making should be appropriate for students' age and developmental levels as in Klein's recommendation to "design writing tasks and strategy instruction by choosing from a series of increasingly sophisticated options, ranging from talk, to informal writing, to forward search strategies [reviewing text to form new inferences] and genre based writing [ex. Halliday & Martin, 1993], to backward search strategies [ex. Flower & Hayes, 1981]" (1999, p. 258).

In summary, writing strategies designed to facilitate links between prior knowledge and experience, conceptual change, and reasoning have the potential to help advance students' skills that function in literacy, by stimulating thought, reflection, self-regulation,

and understanding of scientific concepts, inquiry and argumentation processes. The writing processes undertaken by the writer have been found to influence the resulting product and may ultimately affect learning outcomes. However, if writing strategies are to support all students, the exigency of the task should be considered, aligned with goals and assessments, and appropriately match students' developmental level. Scaffolding may be necessary for some students to direct attention to the rhetorical demands of the task and encourage development of self-monitoring skills as such guidance is considered essential for leading students from the point of knowledge telling to knowledge transformation (Rowell, 1997; Klein, 1999). Scaffolding includes opportunities for interactive discourse, as students perceive social experiences important in helping them understand science concepts and rhetorical demands of the writing tasks. If the rhetorical requirements of writing are less of a burden for students, they might be in a better position to focus on content and use writing as a means to enhance their understanding.

#### Justification

The issues arising from the literature review provided the theoretical framework for design of the investigations enclosed. Some suggestions from the most influential authors and the implications taken from various studies are reemphasized here as they informed and guided the investigations within.

At the time of Rivard's review in 1994, most of the writing research had been conducted at the college level and he suggested that more research was needed in classroom environments to address the relationships between writing and critical thinking and writing and conceptual change. Thus, the following studies targeted these elements and were situated in the classroom. In her review, Rowell (1997) found that "remarkably few studies

give equal attention to the nature of writing tasks, their pedagogical context, and the nature of the science learning" (p. 36), thus we attempted to address each of these elements more fully in the enclosed research reports. Since there is also clearly a need for additional empirical research on writing-to-learn techniques, particularly in how learning is facilitated through the use of writing, a mixed-method approach was used to determine what elements of the writing processes, if any, students identified as beneficial in contributing to learning in interviews and questionnaire responses.

The overarching pedagogical goal, albeit rather broad and a bit ambitious, was to guide students in working toward competency in understanding and applying concepts in science so that these abilities could be transferred for use in future life experiences (Bransford et al., 1999; Hand, Prain, Lawrence & Yore, 1999; Millar & Osborne, 1998; NRC, 1996). With the issue of transferability, by necessity then, the instructional goals were not limited to students' learning of scientific concepts in the units as inquiry and argumentation process are also considered important components of science literacy (Driver, et al., 1994; Kuhn, 1993). With content serving as a canvas, in a sense, the thinking processes involved in these types of activities were considered most relevant to application beyond the classroom. Thus, activities and assessments were designed to help students demonstrate "a working familiarity with the major ideas of science, the confidence to use these ideas to communicate with a variety of audiences, and the ability to assimilate and appraise presented information" (Millar & Osborne, 1998, p. 2025). In reading and writing during inquiry investigations, students practiced scientific literacy in its "fundamental sense" (Norris & Phillips, 2003). However, we conceptualized multiple goals for students, not merely developing understanding in reading or writing about science, but also developing

abilities to communicate, on multiple levels, about science with different audiences. To effectively communicate about a topic is to provide evidence of an understanding of that topic in a way that is clearly understood by an audience (Shamos, 1995; Yager, 1991). Since literacy includes knowledge of language and an understanding of discourse (Flower & Hayes, 1981), scientific literacy, then, also includes a combination of knowledge of language and the rhetorical requirements of writing (Halliday & Martin, 1993) as well as knowledge of the scientific content within the written product (Applebee, 1984). The instructional purpose of the activities was to engage students in developing skills to effectively communicate science content.

While writing can provide "unassailable proof of concept learning" particularly when the student communicates clearly (Ambron, 1991 p. 118), Ambron argued that writing tasks should be used "as a tool for discovery and learning, rather than as a measure of learning" (1987, p. 263). In the studies enclosed, writing tasks were used primarily as tools for learning (Emig, 1977); however, to appropriately assess the kind of learning targeted by these tasks, writing tasks in the form of extended response questions were also used as a means to evaluate students' conceptual understanding. In this way, emphasis was placed on topical knowledge (Applebee, 1984) through communicating understanding of content during the process of completing the writing tasks and also as part of the written responses to questions designed to assess conceptual learning. Indicators of content learning were also evaluated through the use of multiple choice questions, which were primarily recall items on the assessments. The purpose of using both types of questions was to provide more information on "the effects of particular writing experiences on individual learning"

(Applebee, 1984, p. 590), targeting two specific kinds, or quality, of learning that might result from engaging in these tasks.

Several authors have claimed that writing is not typically taught in science classrooms (Martin, 1993; Lemke, 1990; Newell, in press), resulting in a situation that "leads to a tremendous inefficiency in the science curriculum" (Martin, 1993, p. 201). The purpose of the studies enclosed was not to measure learning from writing conceptualized as an isolated act, nor to teach writing didactically, but rather recognized support and guidance as necessary parts of the instructional program (Klein, 1999; Rowell, 1997). Support was implemented through a variety of means in line with the theoretical frame based on an interactive constructivist perspective (Driver, et al., 1994; Henriques, 1997; Yore & Shymansky, 1991). While there were attempts to make writing goals explicit, this was done in combining direct instruction with discussion of these goals (Henriques, 1997; Yore, 2001), due to the primary tenant of constructivism that is, knowledge is actively constructed by individuals (Ernest, 1996; Eisenhart et al, 1996; von Glasersfeld, 1996a). Therefore, we felt that student-centered approaches were also essential scaffolding experiences. Such support helps students navigate meanings of the science concepts targeted in the units and the requirements of the writing tasks as well. Thus, some freedom was afforded to students in navigating the tasks' demands (Prain & Hand, 1996). The socially constructive experiences consisted of the threading of collaborative discourse experiences throughout inquiry, argumentation, and writing activities. During these interactions, the teachers' primary roles were to engage students in practicing scientific thinking and argumentation skills (Driver, et al., 1994; Kuhn, 1993), and utilize and encourage students' use of scaffolding practices during small and whole class group discussions of problem-solving activities, both in laboratory work and writing activities.

Thus, the writing tasks in the teaching units were chosen to "provide students with opportunities to engage each dimension – nature of science, ways of knowing, patterns of argumentation, reasoning, big ideas of science, communications, and evidence" (Hand, Prain, Lawrence, & Yore, 1999, p. 1029).

#### Student-centered Writing Model

To promote student-centeredness during implementation, a writing model designed to assist teachers in scaffolding students' navigation through various writing processes was adopted for the first investigation (Prain & Hand, 1996). The model encourages students to negotiate meanings of the task, concerning both rhetorical and content goals, and promotes the use of a variety of genres. This model supports teachers in their efforts to help students regulate their writing, providing "a framework that recognizes the complex interconnectedness between the demands of different writing tasks and types, subject-topic-task interactions, and student learning outcomes" (p. 618). While pedagogically flexible, in that it is open to choice and decision making by both the teacher and the students, five prompts in the model guide students through structuring their writing task by identifying their topic, the writing type, purpose of the writing, audience for the writing, and method of text production. Since students have an active role in distinguishing among the various components, including attending to various task requirements, such as format, ultimately the locus of control in defining the task is with the students.

To help students formulate and attend to the rhetorical goals of the writing tasks a combination of social approaches and explicit instruction were used. This consisted of providing report guidelines and rubrics to students for guiding both peer reviewing (Chinn & Hilgers, 2002; Galbraith & Rijlaarsdam, 1999) and self-evaluation experiences (Hillocks,



1986; Zimmerman & Risemberg, 1997) in Chapter 4. These alternative experiences were chosen to promote self-monitoring of the writing processes. However, peer reviews and reviews by younger students (Chapter 3) were informed by the social interactive model of writing to help students' attend to the goal of writing to an audience, such as in anticipating any feedback the reader might provide (Nystrand, 1989).

Particularly relevant to the studies in Chapter 4, Keys (1999a & 1999b) argued that evidence of scientific thinking can be found when students attach meaning to their data such as in interpreting their data by forming inferences, constructing new hypotheses, or constructing explanations for the data in their investigations. There is some debate between modern and postmodern perspectives concerning what types of writing tasks best serve learning in science (Prain, 2002). However, in making the case for writing in scientific genres, Keys (1999a) explained such communicative experiences offer "personal ownership of scientific knowledge" and facilitate "understanding the relationship of evidence to knowledge claims, and the tentative nature of the scientific enterprise" (p. 119). Writing in the scientific genre was utilized in the studies in Chapter 4, through both the traditional laboratory report and a highly modified version, the Science Writing Heuristic. A developing research program has informed the choice of this particular task, and because it is somewhat unique, the information this work has provided to date is explored more fully in the next section to further explain and justify its use as a writing tool to support learning in laboratory activities.

#### The Science Writing Heuristic

Guided inquiry was the level chosen for the laboratory activities in Chapter 4. The specific writing guide implemented for laboratory work was the Science Writing Heuristic

(SWH) developed by Hand and Keys (1999), which emphasizes the reflective processes of inquiry and argumentation. The SWH was conceptualized as one form of writing strategy support. In completing the activities with the SWH, students experience science as inquiry and science as argumentation.

The SWH has two main components, one intended for the teacher and the other for students. The teacher template assists the teacher in designing activities before, during, and after the laboratory, to enhance understanding of concepts relevant to students' investigations. The student component consists of the SWH (Figure 2 in Chapter 4), a template to guide students' thinking about the laboratory concepts. The template capitalizes on sequences of two powerful learning strategies, the learning cycle (Karplus, 1977) and conceptual change (Driver, 1988) and the teaching component is reminiscent of the social construction of meaning represented in Gowin's V heuristic (1981, p. 157; Novak & Gowin, 1984). For example, students are oriented to the topic and their initial ideas are elicited by the prompt asking them to share their beginning ideas and make predictions. However, the sequence of each of the phases in the earlier strategies varies with the SWH according to the particular activity and the level of guidance provided. At times, a challenge question might be chosen for students. Other times, students form their own questions. Students work collaboratively during various inquiry processes, negotiating and sharing their ideas while testing questions, collecting data and evidence, formulating explanations using evidence, comparing ideas to alternative sources beyond the textbook, challenging ideas of others through discussion, analyzing contributions, and reflecting on ideas. All of these various activities are in accordance with constructivist learning theory and national science education recommendations (Driver et al., 1994; Millar & Osborne, 1998; NRC, 1996; Yager, 1991).

As students navigate through the set of prompts, students have opportunities to explore and often choose among materials to design their own experiments to test their ideas and also revise or extend their testing as needed. Students might be familiar with concepts relevant to a particular investigation. They might make connections during the process, or they might experience a need to consult external sources in pursuit of more background information or in comparing their ideas to those of their peers, to help explain their findings. Thus, application is part of the full SWH process. Post-activity discussions with the whole class are common. Review also comes during another post-laboratory negotiation phase, in the form of an extended writing activity at the end of a series of investigations. For the individualized reflective writing piece, teachers in past studies have generally chosen a culminating writing task, asking students to relate concepts explored in several completed SWH templates from different laboratories. This writing activity provides opportunities to organize, consolidate, integrate, and refine ideas from several different experiences.

The SWH is unique from other teaching and learning strategies in that it has two templates, one for the teacher and one for the student and also in that it incorporates various modes of learning, collaborative discourse and writing, both used to support development of argumentation during the inquiry process (Keys, Hand, Prain, and Collins, 1999). The SWH also differs from traditional laboratory reports in three important ways (Keys, 2000). For example, writing is threaded throughout the process, before, during and after engaging in hands-on experiences, that is, presenting writing as not purely a display of actions and findings, but a generative process (Osborne & Wittrock, 1983). It also reinforces the collaborative nature of scientific work and writing in science by facilitating negotiations with peers. And finally, the reflective guides stimulate students to make connections between

their observations, data, claims, and evidence, and to compare what they found to reports from external sources. Importantly, the SWH also draws students' attention to reflect on how their beginning ideas have changed as a result of these various experiences, which were not merely physical, hands-on experiences, verbal discourse, reading, or writing, but an integration of all of these.

One important function of the SWH is to help teachers design more student-centered activities by encouraging student ownership of the tasks and shifting control of learning experiences to the students. To this end, the SWH is grounded in constructivism by merging "constructivist theories of learning, the role of prior knowledge, anticipated audiences, reasoning strategies, metacognition and problem solving" (Keys, Hand, Prain, and Collins, 1999, p. 1067). Results from a few studies incorporating the SWH as part of instruction indicate that this template is useful in scaffolding students' inquiry, writing, critical thinking, conceptual understanding and reasoning skills (Hand, Prain, & Wallace, 2002; Hand, Wallace, & Yang, 2004; Keys, Hand, Prain, & Collins, 1999; Rudd, Greenbowe, Hand, & Legge, 2001). Recent research has begun to provide more support for these assertions through analysis of higher cognitive functioning related to science concepts evident in students' writing, analyses of test performance, and metacognitive awareness indicators from questionnaires and interviews.

Past research with the SWH has linked the writing to improvements in students' conceptual understanding of several different science topics in middle, secondary and tertiary levels of education. Enhanced performance on conceptual questions by students who had used the SWH compared to students writing in traditional formats has been found at the university level, with freshman chemistry students studying equilibrium (Rudd, Greenbowe,

Hand, & Legge, 2001), tenth-grade students covering reflection and refraction (Hand, Prain, & Wallace, 2002), and seventh-grade students investigations of cells (Hand, Wallace, & Yang, 2004). Findings from college level SWH students' writings have also shown a greater frequency of science terms compared to control groups (Rudd, Greenbowe, Hand, & Legge, 2001).

Preliminary analysis using effect size also recently indicated low achieving middle-school students benefited from using the SWH concerning performance on both recall and higher-level test items (Gunel, Omar, Grimberg, & Hand, 2003). While students in both control and SWH groups recognized distinct thinking was required in completing different writing tasks, SWH students were more likely to describe learning as they were writing. SWH students also considered answering their own questions valuable for learning compared to control group students' responses to constructing hypotheses. Interestingly, a more in depth analysis of SWH templates completed during a genetics unit indicated that there was no difference between low and high achieving students' usage of cognitive categories in their written reports (Grimberg, Mohammad, & Hand, 2004). These students considered the writing tasks valuable for their learning, reported perceiving ownership of their learning, and confidence in their understanding of claims and evidence.

Additionally, investigations related to the teaching component (Omar & Gunel, 2004; Omar, Hand, & Greenbowe, 2002) have sought to qualitatively characterize the criteria for teachers' successful implementation of the SWH, in terms of how well they facilitate students' oral argumentation by stimulating and sustaining students' active negotiations and interactive dialogue. Pilot study results have indicated that all students across upper grade levels (grades 7, 8, 9, 10, & 12), regardless of their achievement level, studying a variety of

topics (classification, genetics, force, acids and bases) developed better conceptual understandings under higher quality SWH implementers compared to those under lower SWH implementers and students in control groups (Gunel, Akkus, Hohenshell, & Hand, 2004). This study also indicated these effects were large for lower achieving students in particular, under guidance from high implementers.

Interviews from students have indicated that the writing tasks encourage metacognitive awareness as students recognized missing links in their knowledge (Hand, Prain & Wallace, 2002; Hand, Wallace, & Yang, 2004). SWH writing appears to foster a developing awareness of inquiry skills, such as constructing claims, aligning claims with questions, coordination of claims and evidentiary support, and stimulated self reflection on knowledge by choosing among a variety of possible claims (Hand, Prain & Wallace, 2002; Hand, Wallace, & Yang, 2004; Keys, 2000).

To demonstrate support for the assertions, a few cases are presented in some detail. In one study with middle school students, Keys, Hand, Prain, and Collins (1999) found that students furthered their understandings of important nature of science components. While these students did not speak directly to the relationship between data and evidence, they did elaborate their descriptions of how both testing and reflection on evidence played important roles in changing their ideas concerning whether or not a local stream was polluted. Students linked their own data interpretation experiences during discussions to the collaboration and argumentation characteristic of scientists' work. The SWH helped students generate meaning from data, such as in formulating and supporting claims, and making connections between procedures, data, claims and evidence. Importantly, in their written reports, students did not simply generate lists of observations as had been found in a previous study in which

scaffolding experiences for writing were not provided (Keys, 1999b), but instead integrated data and observations to support knowledge claims about water quality and in doing so developed an enriched, personalized understanding of evidence. Students also identified some of the habits of mind (NRC, 1996) such as effort, patience, and persistence in describing their own endeavors and related these to scientists' attributes, describing in some detail important characteristics that otherwise appear rather elusive in the literature.

The second paper in this dissertation (Chapter 4) was modeled after a study with middle school students also studying the topic of cells (Hand, Wallace, & Yang, 2004); although the enclosed study sought to address slightly different questions; thus, the designs were not identical. The study with seventh grade students utilized three student groupings, and two different writing types. Students in the control group wrote three traditional laboratory reports and a summary report to the teacher. Students in an SWH group differed only from the control group in completing their written lab activities using the SWH template. The last group used the SWH during laboratories and wrote their summary reports in the form of a textbook to an audience of their peers. Framework guides were provided for both writing types and students had opportunities to revise their summary writings after receiving feedback from their peers. Quantitative findings indicated that students in both SWH groups performed better than control group students on one conceptual question measure and multiple choice items, which was important because differences on lower order recall questions had not been found in a previous study with high school students (Hand, Prain & Wallace, 2002). Students in the SWH group who wrote textbook summaries also performed better than the other two groups on two different conceptual questions.

Interviewed students reported that formulating their own questions was a major factor contributing to their learning and also perceived benefits from group discussions and opportunities to connect concepts in writing (Hand, Wallace, & Yang, 2004). Metacognitive awareness was indicated by students' recognition that in organizing their writing they had to figure out what they did not know and students completing the textbook summary reported rewording technical language to meet the needs of their audience. While writing guides provided opportunities for backward searching strategies (Klein, 1999), the translation required in constructing explanations for their peers helped students to recognize knowledge gaps, which combined with making connections between concepts and their own understandings indicated these students were using forward search mechanisms described by Klein (1999).

Wallace (2004) expanded the data analysis from the Hand, Wallace & Yang (2004) study to explore the cognitive and metacognitive mechanisms employed by six targeted students. Results from interviews and written products (SWH, summary and essay test items) indicated the students used sources of knowledge that matched their epistemologies. For example, students expressing naïve views limited their explanations to what they observed and the inferences they made from concrete activities. Additional cognitive mechanisms used consisted of peers' ideas, explanations, syntheses and reflection on own ideas and authoritative sources, and integrating students compared their observations to their textbook source. Wallace suggested that more explicit guidance be provided during the discursive discourses, and also specifically guiding both reading and talking to access sources for ideas, to clarify how these experiences might differ from other classroom discussions, all of which might help students better integrate information from authoritative



sources and direct observations. In addition, she recommended teachers consider adjusting the rubric credit to reward clear distinctions and appropriate use of claims and evidence.

While these various findings in research with the SWH are exciting and promising, the ability to generalize these results is limited for a number of reasons. These were small scale studies of a limited number of classroom experiences, while the writing tasks were similar in that students utilized the SWH during laboratories, the topics in the units differed and more research is needed on a wider variety of topics to determine if certain topics or concepts are better suited to this kind of support. In the studies with students successfully demonstrating advanced cognition after using the SWH, most teachers were generally familiar with the SWH program, had graduate course work in constructivism and science literacy, and had a network of support from researchers during the process of incorporating the SWH into their curriculum for the purpose of study. Although it is likely these teachers would rank at a high level of implementation due to the support they experienced and extended practice using the SWH, since not all were observed directly, more research is needed to secure the link between teacher and student performances. Additionally, more research is needed with a larger population composed of diverse students to determine if positive outcomes can be replicated in different environments.

Table 1. Synthesis of classification schemes for various constructivism forms by metaphysical commitments, motivation, methodology and pedagogy (modified from <sup>a</sup>Ernest, 1996; <sup>b</sup>Eisenhart, Finkel, & Marion, 1996; <sup>c</sup>Yore, 1999).

Form	Ontology <sup>a</sup>	Epistemology <sup>a</sup>	Epistemic View of Science <sup>c</sup>	Motivation to Learn <sup>b</sup>	Research/Methodology <sup>a</sup>	Pedagogical Emphases <sup>a</sup>
Weak/ Cognitive/ Piagetian	Realism	Dual Individual Focus Objective knowledge realm/Absolutist/Certainty	*Dual Relativist/ Absolutist	Individual Material/Content	neopositivist	Previous ideas/ Active construction
Radical	<i>Neutral</i> Subjective Experience	Individual Focus Relativist/ Fallibilist/Uncertainty	Relativist/ Postmodern	Individual Material/Content	Reflexive approach	Previous ideas/ Active construction Experiences
Social	Shared/Social Modified Relativist	Social & Individual or All Social Focus Fallibilist/Uncertainty	Evaluativist/ Postmodern	Identity & Resources (through doing)	Reflexive approach/ Eclectic	Eclectic; Radical + Discussion, Collaboration, Negotiation, Community participation
Interactive <sup>c</sup>	<i>Hybrid</i>	*Hybrid; Social & Individual Public & Private realms Objective pursuit Relativist/Uncertainty	<i>Evaluativist/ Modern</i>	*Individual & Interactions Intrinsic desire for clarity (through seeking & doing) through negotiations	*Reflexive but Subject to Evaluativist Critique with Modernist Criteria	Eclectic, Social + Argument, Direct instruction, Consolidation

Note. <sup>a, b, c</sup> indicates primary source; row superscript takes priority, \* indicates category absent in primary source and moderately deduced by the present author.

### CHAPTER 3. EXPLORING STUDENTS' RESPONSES TO CONCEPTUAL QUESTIONS WHEN ENGAGED WITH PLANNED WRITING EXPERIENCES: A STUDY WITH YEAR 10 SCIENCE STUDENTS

A paper published in the Journal for Research in Science Teaching

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#### Abstract

Whereas there has been strong advocacy of the value of writing for learning in science, the role of student planning in this approach, and the relationships between planning, writing, and learning, have been underresearched. Our mixed method study aimed to address this issue by seeking to identify any quantitative differences in learning outcomes between two groups of students exposed to varying degrees of planning activities in writing-to-learn experiences. We also identified differences in learning outcomes between a group of students with two writing experiences and a group with one writing experience. Results indicate that students with planned writing activities did not score significantly better on conceptual questions as a group than students who had delayed planning experiences. Students with two writing experiences as opposed to one scored significantly better as a group on answering conceptual questions both immediately after the writing experience and on a test 8 weeks after the unit. The difference in writing treatment initially significantly impacted males compared to females, but this effect disappeared with further opportunities to write. Students' comments provide support for using non-traditional writing tasks as a means to assist learning, particularly when the focus is on a different audience to the teacher. In reporting on different learning outcomes for the two groups, we consider various implications including identification of some key conditions for student writing to serve learning.

### Introduction

There have been various recent accounts of the benefits of writing for learning in science (Champagne & Kouba, 1999; Hand, Prain, Lawrence, & Yore, 1999; Kelly & Chen, 1999). These authors claimed that writing can induct students into the reasoning skills necessary for scientific inquiry, and can also provide an effective means to assess students' thinking and conceptual knowledge in science. Acceptance of the value of writing is evident in recent science teacher text-books (Ebernezer & Haggerty, 1999; Johnson & Raven, 1999, p. 45; Krajcik, Czerniak, & Berger, 1999), which propose such writing topics as the following: "Write and perform a series of skits for your class to demonstrate the unique properties of water that make water essential for life." Students are now expected to write stories, poetry, biographies, and reports in science on the assumption that they already have the necessary knowledge, skills, and planning strategies to succeed with these tasks.

However, recent reviews of the research literature on writing for learning have identified various problems (Galbraith & Torrance, 1999; Holliday, Yore, & Alvermann, 1994; Klein, 1999; Rivard, 1994). Rivard noted that much past research entailed small-scale qualitative studies that failed to establish quantifiable evidence of learning benefits across different classroom contexts and topics. Holliday, Yore, and Alvermann (1994) noted that there was still a need for research on writing emphasizing "exploration, expressive inquiry, discovery, problem-solving, decision-making, and knowledge construction" (p. 885), as "current conceptions of writing to learn appear to be embryonic and fragmented" (p. 885). Klein (1999) asserted that research to date had failed to establish how writing served learning, with the possible exception of genre-based studies that indicate student knowledge of generic structures enable them to see "relationships among ideas" (p. 204). Klein (1999)

suggested that more research is needed to establish the effects on learning through writing when students were given “full writing strategy support” (p. 260), which includes procedural knowledge about planning specific writing tasks. Galbraith and Torrance (1999), following Hayes and Nash (1996), contested this view about the centrality of planning in learning through writing, claiming that other factors, such as topical knowledge, linguistic skills, and motivation, also might explain success in writing. In an earlier study, Galbraith (1992) claimed that planning enabled writers to develop new ideas only when the writers focused on solving rhetorical issues of effective communication. This general discussion about the role of planning in writing has focused mainly on quality of writing outcomes rather than on quality of learning. As a result, there is a need for research on writing-to-learn science that links writing with learning outcomes and identifies the most appropriate teaching strategies and environments that support learning through writing. The present study sought to address this need.

In a recent comprehensive overview of the dominant theories of how writing might enhance learning, Klein (1999) claimed that these explanations could be categorized into four broad groupings, each of which describes the role of planning. These four explanations were writing as “spontaneous utterance,” the “forward search hypotheses,” the “genre-related hypotheses,” and the “backward search hypotheses” (p. 208-209). Spontaneous utterance was attributed to Britton (1982), who argued that student writing shapes thought in the act of expression, making tacit understandings more explicit. The forward search hypotheses were attributed to Bruner (1966), Emig (1977), and Donald (1991) because these theorists asserted that writers transform their ideas by ongoing analyses of their texts in terms of expanding inferences, reviewing idea development, noting contradictions, and making appropriate

revisions. Bereiter and Scardamalia (1987), Halliday and Martin (1993), and Hayes (1987) were among several of those identified as contributing to the genre-related hypotheses, which maintains that the use of different generic frameworks and knowledge of the micro and macro structure of texts enables students to identify the relationships between ideas and clarify understanding of content. The backward search hypotheses, which Klein attributed to Flower and Hayes (1980; 1984), Vygotsky (1962), and Bruner (1966), among others, argue that students learn through writing by setting and addressing rhetorical and content goals. While forward search strategies focus primarily on the initial generation of text, backward search strategies focus mainly on checking the success of an advanced draft in terms of achieving coherence and persuasiveness, although such strategies also entail initial planning and text generation in terms of rhetorical goals. In a study with elementary students to examine these hypotheses, Klein (2000) indicated that forward search strategies were beneficial in helping students construct understanding, although he did suggest that the backward strategies were more effective in helping these students. Students were able to use both forward and backward search strategies, that is, these strategies are not totally independent of each other. He recognized that there is a greater cognitive involvement required from students when using these “multiple strategies” (Klein, 2000, p. 344).

Klein (1999) also analyzed the relative importance of planning in each hypothesis. The spontaneous utterance hypothesis implies that students can learn from writing when no overt planning or revision takes place. Klein claimed that the evidence concerning this hypothesis suggested that this writing could contribute to learning, but only by “assimilating new experiences to existing concepts rather than changing these concepts” (p. 212). He noted that employing “existing linguistic resources in an unreflective and, therefore, uncritical

fashion” does little to challenge students’ preconceptions (p. 219). In contrast, the forward search hypothesis treats the writer’s emerging text as the plan that can be revised. In this hypothesis, revision strategies are used to address contradictions in the text, which constitute the means through which writing promotes new learning. Written text allows for inspection and revision, which enables knowledge transformation, new insights, and possible conceptual change for the writer. For Galbraith (1992), the writer’s disposition towards the topic implies a tacit “plan” of attack and revision of this plan provides engagement that has the potential to allow new insights and dispositional change to occur. Klein claimed that there was only limited research evidence that linked textual revision with learning. While there was evidence that expert writers improved the coherence of their texts through revision, this might reflect the development of procedural knowledge to improve the quality of writing and may not indicate gains in conceptual knowledge.

The genre-based hypothesis assumes learning occurs when writers address the purposes, demands, and strategies of particular genres. Attention to these aspects is evident in a focus on micro and macro structures of texts, and thus theorists claim that writers “process information deeply” as they “construct relationships among ideas” (Klein, 1999, p. 230). McGinley and Tierney (1989) claimed that students could strengthen their understanding of topics by writing about the same topic using different genres. However, Klein claimed that variation in students’ understandings of the goals, strategies, and means through which coherence is achieved in different genres may be responsible for the mixed results of investigations concerning the effects particular genres have on learning outcomes. Klein suggested that more research is needed to determine how students engage with writing in different genres. This issue raises the further question of how the teacher’s focus during

instruction of genre-based writing influences learning and the role those particular kinds of planning might play in this process. Klein also observed that learning might be influenced by students' prior knowledge of a topic and the specific logical processes they apply to problem solving.

In the backward search hypothesis, writers learn by setting rhetorical goals, generating content to meet these goals, and then revising rhetorical goals to address emerging content. In an analysis of the models proposed by Flower and Hayes (1980) and Bereiter and Scardamalia (1987), Klein (1999) identified a variety of planning heuristics that writers might use to solve problems, generate and focus goals, and build or transform content. These included generating lists of ideas on topics, thinking aloud strategies, creating sub-goals from high-level goals, and developing two opposing views on a topic. According to these theorists, the planning and revision activities promote learning by linking a focus on content clarification with rhetorical concerns about how content can be communicated effectively to specific readers. The planning activity recently has been conceptualized by Zimmerman and Risemberg (1997) to involve three cognitive subcomponents, "generating information that might be included in the composition, setting goals for the composition, and organizing the information that is retrieved from memory" (p. 74). Effective writers also are aware of, and match their goals to, the discourse expectations and understandings of their target audience (Galbraith & Rijlaarsdam, 1999). Attention to audience is important, according to Ferrari, Bouffard, and Rainville (1998), who have suggested that along with a better understanding of the rhetorical and linguistic demands of writing, expert writers appear to "have a clear appreciation of how one's goal in writing will be received by one's audience" (p. 486). Additionally, Best (1995) stated that "expert writers seemed to synthesize information, re-



arrange their material and locate what may appear weak, to prepare prose which accommodates the reader” (p. 9). Research on expert writers’ composing processes has focused on the issue of producing rhetorically effective writing, and Klein acknowledged that meeting these goals also might affect the writer’s subject knowledge. However, he claimed that research to date had failed to verify that these backward search processes necessarily had this effect, indicating that more empirical testing and analyses are required to examine the link between writing-to-learn strategies and knowledge transformation processes.

In summary, Klein argued that these four broad hypotheses need further research substantiation. Most importantly, he asserted that each set of hypotheses tended to assume students already had the relevant procedural and conceptual knowledge necessary to engage with writing in the way proposed by each set, whereas he claimed that students probably needed far more teacher-directed support and guidance. We concur with his assertions and our research was guided by the view that effective planning experiences can provide students with the necessary knowledge to meet task demands. Klein (1999) explained that the four hypotheses “invoke different aspects of writing, and so are mutually compatible”, even if these “four dimensions of writing are partially independent of one another” (p. 210-211). This claim leaves open the possibility of integrating elements of each explanation into a more comprehensive model of writing, revealing the various ways in which writing might support both procedural and conceptual learning. To this end Klein suggested that educators should design writing tasks and strategy instruction that include planning and composing options proposed in each set of hypotheses, especially with a focus on genre-based writing and forward search. Our research project sought to identify the value to students’ learning when

they engaged in forward and backward search strategies with one genre, rather than across different genres.

Other theorists, such as Galbraith and Torrance (1999), have expressed various concerns about a focus on problem solving as the key feature of the writing process. They claimed that this emphasis failed to acknowledge the importance of contextual and social factors such as the learning environment and the writer's knowledge about, and attitude toward, the task. They argued that all aspects of text production do not operate in a rational, top-down, goal-driven way, as implied by a problem-solving model, and that the interaction of other factors such as content and discourse knowledge, linguistic skill, and motivation, may explain writing success or failure. Following Hayes and Nash (1996), they noted that research on planning, a key element in a problem-solving focus, had not established that this factor is crucial to writing success. In their overview of research into planning for writing, Hayes and Nash (1996, p. 54) also noted that much past research failed to "distinguish between content and non-content planning," and also failed to substantiate claims that more planning led to improved writing. Galbraith and Torrance (1999, p. 7) concluded that, while a problem-solving focus contributed to an understanding of text production, there was a need to change our conception of writing as a "controlled, rational process," and to acknowledge more diverse factors in text production.

Attention to the language used in writing is likely another important factor in learning. Lemke (1990) noted the key role of verbal language for students in negotiating the meaning of scientific terminology, concepts and activity. Sutton (1992) claimed that students' beliefs about the nature of scientific knowledge is strongly linked to their beliefs about the language of science, where students assume that specific terminology confirms the objective

reality of the concepts to which the language refers. He argued that changes to these fixed and narrow epistemological assumptions could be achieved only by altering student perception of the nature of the concepts in science, and their relationship to both technical and everyday language. He suggested that students be provided with various opportunities to explain and justify their understanding of science as well as explain their understandings of science's technical language. In Sutton's view, students need to be set writing tasks that require a focus on translation, where students explain, elaborate, and integrate their understandings of specific science concepts using more than just the technical vocabulary of the subject.

#### Research Context

These points raised in the review of the literature on planning in relation to writing have informed our research project's focus. Our research project sought to provide planning opportunities aligned with Klein's summarized hypotheses, with a particular focus on forward and backward searching, supported by some guidance in genre-based writing. The program provided opportunities for students to engage in forward and backward search in using writing and re-writing to clarify their understanding, and students were also given broad generic templates to serve as a guide for this writing. These templates were designed to provide only general rather than highly prescriptive guidelines to encourage student initiative and ownership of the task. Support for students was conceptualized in this research as the provision of generic templates, time for independent research, and a range of planning and reporting activities in which students received both student and teacher feedback on their draft texts. Past studies too often have focused on the implementation of one writing task using one method set. To contribute to a deeper theoretical understanding of the value of

planning in writing for learning, the present study examined the effects of different kinds of planning types, sequences, and activities.

Drawing on the general review of the nature of planning in relation to writing and learning, we conceptualized planning as all of the cognitive activities involved in verbal and written outcomes during which students negotiate current and emerging understandings to meet the demands of a particular task. We perceived planning to include various individual, small group, and whole-class activities in which students negotiated their understanding of individual and shared meanings about the target concepts. In this way the study sought to identify quantitative and qualitative learning gains when students engaged in environments that provided “full writing strategy support” (Klein, 1999, p. 260). Our decision to use planning strategies was based upon Galbraith’s (1992) findings that student planning had the potential to have a positive effect on writing task performance, depending on the students’ self-monitoring strategies. We decided to set up two contrasting planning experiences for students to build upon Galbraith’s study, which was designed for a single, one-off writing task, and to apply these strategies within the context of a science topic with the intent of the task to be a component of the teaching strategies dealing with conceptual knowledge of the topic. Another purpose was to contrast a planning strategy against one normally used with writing tasks in secondary science classrooms, that is, one with very little guidance.

Although there is now general agreement that writing in itself does not necessarily result in learning (Klein, 1999; Rivard, 1994; Schumacher & Nash, 1991), there is still a need to identify how learning may occur with writing and how this may be influenced by the teacher and the various processes of writing that students experience. The present study draws on past research that sought to identify the effects of diversification of writing tasks on

students' attitudes toward learning science and performance (Prain & Hand, 1999; Hand, Prain, & Keys, 1999). This prior research found that students who tackled extended writing tasks performed better on higher order conceptual questions than did students in traditional programs.

The quantitative component of the present study sought to address two research questions: (a) Do students experiencing planning sequences prior to writing perform better on conceptual measures of content knowledge than do students with delayed-planning experiences; and (b) is there a cumulative benefit to be gained from using multiple, non-traditional writing tasks? The qualitative component of the study was centred on determining students' perception of the cognitive and metacognitive processes associated with using writing-to-learn strategies. As such the qualitative component of the study sought to identify (a) students' perceptions of how they attempted to address the demands of specific writing tasks, and (b) students' perceptions of the consequences of their engagement in this kind of writing task.

### Research Design

This study involved collaboration between two researchers and two teachers; one researcher was an English educator and one a science educator, and the teachers included a male with 27 years of teaching experience and a female with one year of teaching experience. This collaboration entailed development of the second semester biotechnology unit, regular weekly group meetings, classroom observations and debriefing sessions, and development of testing instruments to examine the learning outcomes from using writing. The content knowledge addressed within the six-week teaching unit was centered on three major concepts that were used to frame the teaching/learning experience. These concepts included: (a) the

universality of DNA, that is, DNA is the hereditary material found in all living organisms according to the cell-biology theory of life; (b) DNA contains codes that produce proteins influencing organisms' traits; and (c) there are social and ethical issues concerning genetic engineering. These concepts were used both as an organizing framework for the teachers and as a guide for students to reflect upon in terms of learning outcomes for the unit.

A mixed method approach was used for this study. For the quantitative component a quasi-experimental, post-test only, co-relational design, with four independent groups, was used. For the qualitative component, semi-structured interviews were conducted with selected students from each class.

#### Participants

Four classes of tenth-grade biology students ( $N = 73$ ), from a predominantly white, middle-class junior-senior high school participated in this study. The school is a rural high school in Iowa with a population of 611 students in grades seven through twelve.

Information on students' classroom performance in the semester prior to the study was collected and used as baseline data for this experiment. The baseline for each student was computed using scores from the end of semester test, topic tests, laboratory reports, and homework recorded in semester one. The topics covered during the previous semester consisted of material related to the nature of science, chemistry, cell biology, and genetics, which provided important background information for biotechnology, the unit of study in this project. The mean baseline score of each of the four classes were used to identify each class as either a group one class ( $\underline{M} = 84.25$ ,  $\underline{SD} = 10.48$ ,  $\underline{n} = 16$ ; and  $\underline{M} = 82.21$ ,  $\underline{SD} = 7.38$ ,  $\underline{n} = 19$ ) or a group two class ( $\underline{M} = 79.22$ ,  $\underline{SD} = 10.09$ ,  $\underline{n} = 18$ ; and  $\underline{M} = 80.75$ ,  $\underline{SD} = 8.03$ ,  $\underline{n} = 20$ ). While the means were different, ANOVA indicated the mean baseline scores did not differ

among the four class groups. Even so, these groups were used to randomly assign treatments so that both treatments of planning sequence and number of writing experiences (further distinguished below) were balanced among group one and two classes. Treatments also were balanced between the two teachers, who were assigned to the classes so that each taught one class of each treatment.

The research design centered on providing students with different writing experiences, both in terms of the sequence of planning activities and the number and type of writing tasks. The treatments were characterized by the sequence of planning activities, which was distinguished as the planned (PL) or delayed-planned (DPL) group, and the number of writing tasks, for which students wrote once (1WR group) or twice (2WR group). Student composition in each treatment group is listed in Table 1.

Table 1. Number of Students per Treatment Characterized by the Type of Planning and Number of Writing Tasks

Planning Groups	Number of Writing Tasks	Class Size	Females	Males
PL <sup>a</sup>	2WR <sup>c</sup>	19	9	10
DPL <sup>b</sup>	1WR <sup>d</sup>	18	7	11
PL <sup>a</sup>	1WR <sup>d</sup>	20	9	11
DPL <sup>b</sup>	2WR <sup>c</sup>	16	6	10

<sup>a</sup>Planned groups (PL) with immediate planning experiences.

<sup>b</sup>Delayed-planned groups (DPL) with planning experiences after writing the initial draft.

<sup>c</sup>Groups with two writing tasks (2WR) assigned.

<sup>d</sup>Groups with one writing task (1WR) assigned.

### Sequence of Planning Activities

The sequence of planning activities was characterized by either planned writing experiences (PL) or delayed-planned writing experiences (DPL). For the purposes of this study, the DPL group was differentiated from the PL group by the contrasting classroom sequence (Table 2), in that the PL group had earlier access to the writing template and planning activities. The full sequence of planning activities for the students completing two writing tasks (2WR group) is outlined in Table 2. The major difference between the PL and DPL groups was the order of planning activities prior to writing the first drafts. Students in DPL group were asked to research their topic and complete a first draft of the textbook without initial exposure to the organized planning steps. It is this sequence that was used previously by the teachers in the study and we considered it to be a typical practice for secondary school science writing activities. After completing their first drafts these students then were provided with the same planning activities that students in the PL group had received prior to their first draft.

Table 2. Differences in the Sequence of Planning Activities between Planned (PL) and Delayed-Planned (DPL) Groups

Planned (PL) Group	Delayed-planned (DPL) Group
Received template for Writing Task 1	Received template for Writing Task 1
Researched in groups	Researched in groups
Planned presentation	Wrote 1 <sup>st</sup> draft
Presented in groups	Received feedback on 1 <sup>st</sup> draft
Received feedback from class	Planned presentation



Refined ideas	Presented in groups
Wrote 1 <sup>st</sup> draft	Received feedback from class
Received feedback on 1 <sup>st</sup> draft	Refined ideas
Wrote final draft	Wrote final draft
Exam 1	Exam 1
Received Writing Task 2	Received Writing Task 2
Planned task in groups	Wrote 1 <sup>st</sup> draft
Wrote 1 <sup>st</sup> draft	Planned task in groups
Received feedback/revised ideas	Received feedback/revised ideas
Wrote final draft	Wrote final draft
Exam 2	Exam 2
Exam 3 (delayed post-test)	Exam 3 (delayed post-test)

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For Task 1, students in the PL group were provided with a series of steps to be completed before attempting to write their first drafts. These steps included: (1) using a template (see Figure 1) to plan their writing task, which was introduced by their English teacher; (2) researching on the topic; (3) discussing major ideas for their topic in small groups; (4) presenting their ideas to the whole class with feedback being provided by their peers; (5) reviewing peer feedback in small groups; and (6) confirming their understanding of the ideas under review in small group discussions. Each of these steps also could be characterized as fitting Klein's (1999) four categories for explaining how writing serves learning (Table 3). While more than one hypothesis set can be identified in each planning

task, the whole process intended to provide students with opportunities to use cognitive strategies implied by each hypothesis.

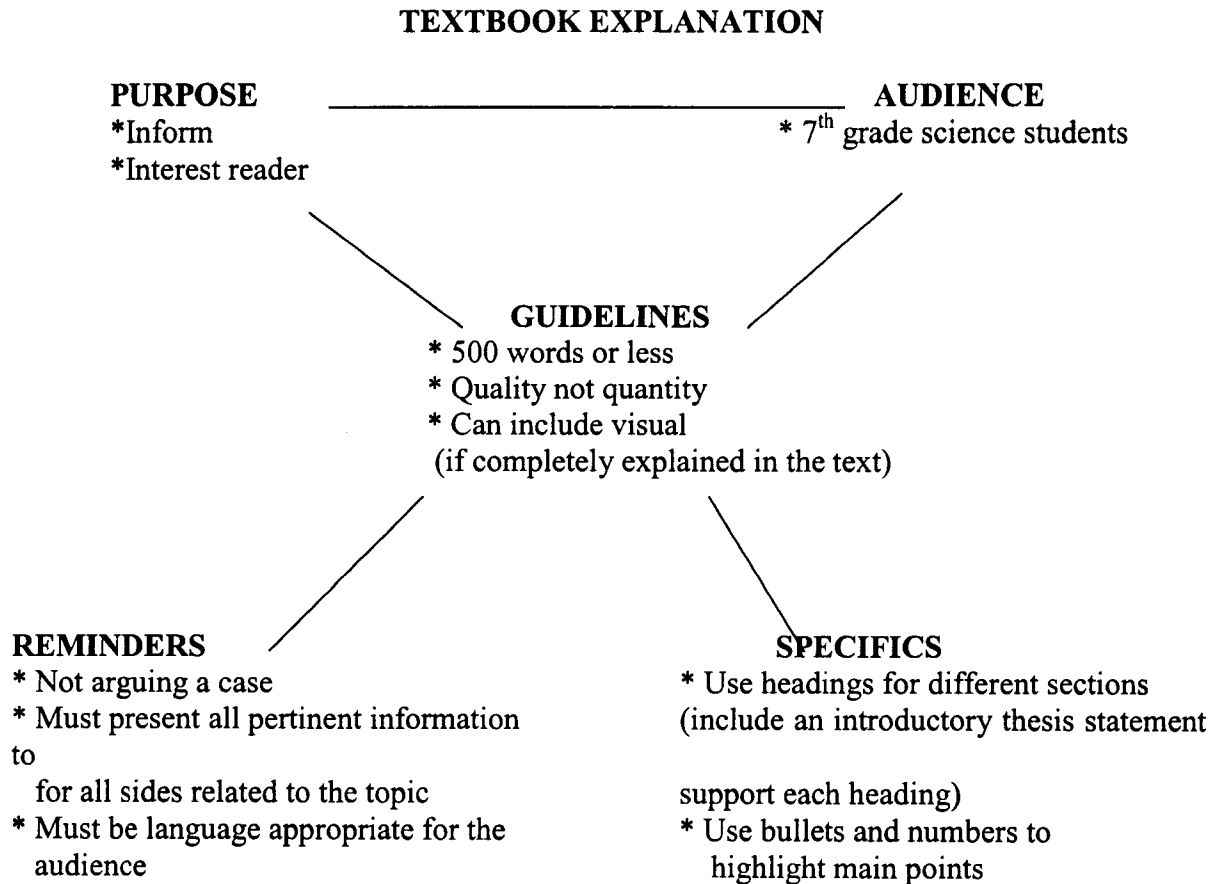


Figure 1. Handout provided to students from the English teacher for guidance in writing the textbook explanation for year 7 students.

Table 3. Planning Tasks in Relation to Klein's (1999) Categories

Planning Task	Hypotheses of Writing-to-Learn
1. Use of template	Genre-based
2. Research on topic	Forward search
3. Small group discussion	Forward search
4. Presentation to whole class	Forward search/backward search
5. Review of feedback	Forward search/backward search
6. Small group discussion	Backward search

#### Number and Type of Writing Tasks

To identify possible learning gains from cumulative writing tasks, the number of writing tasks also differed among the four classes. Students in one DPL class and one PL class completed one writing task (1WR group), while students in the remaining PL and DPL classes completed two writing tasks (2WR group). Task 1 consisted of writing a textbook explanation on a biotechnology topic for an audience of seventh-grade students. Final drafts produced by the students were given to Year 7 students for evaluation. Task 2 consisted of writing a newspaper article for the general public, with final drafts being given to the editor of the local newspaper for comment. Both of these writing tasks were considered “non-traditional” because they were not part of the normal science curriculum and because emphasis was placed on involving the target audience in a function of providing real feedback to the students.

All students were required to complete the same laboratory activities and the first nontraditional writing task, Task 1. Only half of these students (those in the 2WR group) were asked to complete another non-traditional writing type (Task 2), further expanding on their ideas as outlined in the previous textbook explanation. Students in the 2WR group used the same PL and DPL experiences as outlined for the textbook explanation, with the exception that they were not visited again by the English teacher because they were already familiar with the template. In lieu, a local newspaper reporter led a discussion about the important elements of a newspaper article.

Students in the 1WR group did not experience the instructional activities for Task 2. During this time, students in the 1WR group worked on more traditional assignments, taking notes from the blackboard and completing a study guide addressing the same biotechnology concepts. In other words, students in 1WR did not participate in any further non-traditional writing tasks as part of their science learning; instead these students engaged in short, traditional writing tasks. Time on task for 1WR and 2WR groups was equivalent as students in 1WR were allocated the same amount of time in completing their more traditional writing tasks as students in 2WR when completing the second writing task. The purpose of each of these two different writing tasks was to ensure that the major concepts addressed in the unit were reviewed by the students—that is, both tasks were viewed as being meaningful tasks.

#### Assessment

The first drafts of the textbook explanation (Task 1) were assessed for content by the science teacher (see Figure 2) and for rhetorical effectiveness by the English teacher, both of who provided written feedback on each student draft. The students were provided with opportunities to discuss the feedback from these teachers within their groups before

completing a redrafted copy, which subsequently was scored by both teachers and used for data analysis. Figures 3 and 4 provide examples of student's finished products.

Content	0	1	2	3	Total
Topic description /definition	Absent	Inaccurate	Adequate	Accurate and Complete	3
DNA-Description /definition	Absent	Inaccurate	Adequate	X	2
DNA-University	Absent	Included	Relevant	X	2
Gene Expression-Defined	Absent	Incomplete or Inaccurate	Adequate	X	2
Gene Expression-Described the process	Absent	Inaccurate	Incomplete	Complete	3
Example used	Absent	Included	Relevant	X	2
Ethics-Pros	Absent	Included	X	X	1
Ethics-Cons	Absent	Included	X	X	1
Ethics-DNA manipulation controversy	Absent	Included	X	X	1
Links-flow between concept	Absent	Some	Most	All	3
TOTAL					20

Figure 2. Rubric used by the science teacher to provide feedback to the students on their first draft and to score their final draft.

### **Biotechnology and Medicine**

Do you know what biotechnology is? Well Biotechnology is a term for managing biological systems for human benefit. The most common is Genetic Engineering which involves the genes of all living things. Medicine is the science and art of healing. Medicine is knowledge gained by study and experimentation. It is an art because it depends on how skillfully doctors and other workers apply their knowledge to the patients. The goals of medicine are to save patients lives, to relieve pain and to maintain the dignity of all ill patients. A number of human illnesses are caused by the failure of certain genes in the body that make proteins. One example would be the failure of genes in the pancreas to make insulin causes diabetes. Scientists can produce insulin in bacterial factories by putting in the insulin gene from human cells to plasmids from cells of *Escherichia coli* bacteria. The insulin is then given to the patients who need it. Researchers also have engineered *E. coli* to make proteins called interferon's. These proteins are normally produced by body cells in response to viral infections. Many people suffer from diseases caused by genetic defects. Using recombinant-DNA isolated from cells of unborn babies to learn whether the babies will have a disease. Also, researchers have found methods of gene therapy to cure diseases. Doctors first used gene therapy to treat a patient in the 1990. The patient suffered from weak immune system. Since then lots of clinical trials are used during gene therapy. Gene therapy has been tested for use as treatment of many disorders, including cancer, cystic fibrosis, and the overproduction of cholesterol.

Figure 3. Christina's (DPL, L) textbook explanation for her biotechnology writing tasks.

Figure 4. Corey's (PL, H) textbook explanation for his biotechnology-writing task.

## **Genetically Modified Organisms for Food**

### **Chapter 7**

**7.1** Genetically modified organisms that are used for food can be animals, plants and etc. To make them genetically modified all they have to do is make a change in the DNA<sup>1</sup> to produce a special protein. DNA is found in all organisms, and that would be the reason why scientists work with the DNA to modify the organisms. First, the scientists find the target cell; they then take the DNA out of the cell and transfer it into a host or a **bioreactor**<sup>2</sup>, commonly with a **gene gun**<sup>3</sup>. That is one way scientists genetically modify an organism.

#### **Modified Foods**

**7.2** Genetically modified organisms are showing up more and more as the years go by. They genetically modify organisms for many reasons. One of those is modifying food to make it better. The USA is the most productive country in this field. They modify many different foods. Some of these include tomatoes, squash, yeast, corn, potatoes, and soybeans. All of these are used in 60% of all processed foods, such as bread, pasta, ice cream, pies, margarine, cheese and many meat products. This process has bettered a lot of foods and will continue for a while.

#### **Example of a Genetically Modified Organism for Food**

**7.3** There is a special tomato out there that has been especially modified. This tomato is called the FLAVR SAVR Tomato. The Calgene Company of Davis, California modified this FLAVR SAVR Tomato. The way they modified the tomato was by flipping over the **gene**<sup>4</sup> that causes it to rot. In August of 1992, the Food and Drug Administration, also known as the FDA gave the Calgene Company the go-ahead to begin a full-scaled production of this glorious tomato.

#### **Pros and Cons**

**7.4** Modified organisms can be good and can also be bad. By modifying organisms they run the risk of creating new toxins in food, an increase in water contamination, the spread of diseases, nuclear pollution and global warming. Those were just a few serious consequences for modifying organisms. Although there are a lot of things that are affected in a bad way, there are many good ones. Good ones such as, better-processed foods, enhanced food value, and resistance against weeds.

#### **Opinion's on Genetically Modifying Organism**

**7.5** Many scientists think that modifying organisms is bad and that no one should mess with the DNA of any organism. On the other hand, there are scientists that believe that modifying organisms is a great thing and that it will help us cure certain defects in the DNA. They also think that this will lead us into a new life filled with new discoveries. It is all in everybody's opinion. What do you think?

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<sup>1</sup> DNA: The sequence of amino acids and base pairs that make up the specific organism's traits and characteristics.

<sup>2</sup> Bioreactor: An animal or bacteria that you insert the DNA of another organism into, to modify it and produce the certain protein needed.

<sup>3</sup> Gene Gun: A move tool that shoots DNA coded pellets into the host or bioreactor.

<sup>4</sup> Gene: The recipe for a protein.

After redrafting Task 1, all students completed Exam 1, consisting of 12 recall questions and three conceptual questions. Instruction for the unit ended after the students in the 2WR group completed Task 2. At the end of the six week unit all students then completed Exam 2, consisting of five recall questions and another three conceptual questions, which were worded differently from those on Exam 1, but targeted the same concepts. Eight weeks after completing the unit all students also completed Exam 3, the end of the semester final exam, which included three conceptual questions related to the biotechnology unit. Examples of conceptual questions included, “(1) You are a researcher trying to solve a genetic defect where a sufferer can’t produce an enzyme they need to survive. Please explain how you would solve the problem using genetic engineering techniques and why your solution would be effective, (2) You did such a wonderful job with your explanation to the seventh graders, the school board has asked you to explain to a parent group how gene expression, DNA and protein are related, and (3) You are a researcher trying to solve a genetic defect in which a patient can’t produce an enzyme needed to survive. Please explain how you would solve the problem using genetic engineering techniques. What condition would you use to determine your success?” All exam questions were scored by the two teachers involved in the study.

### Quantitative Component

This section describes the validity and reliability of baseline measures as well as the dependent variables collected and used in the quantitative analyses.

#### Baseline Validity and Reliability

Three independent researchers analysed the distribution of scores from the previous semester used to calculate the baseline scores and determined that these assignments were



well weighted. These researchers also determined the face validity of one full unit test used to calculate the baseline scores by assessing items on assignments and the test, and concluded that these were valid measures of the objectives for this unit. The content knowledge recall test from semester one was tested for reliability using standardized Cronbach alpha; an internal consistency of .81 was obtained.

#### Dependent Variables

Data were collected from scores on students' writing tasks and exams; Table 4 provides a description of all of the dependent variables in the order that data was collected. The dependent variables included scores on Science mark on Task 1 (Tk1S), English mark on Task 1 (Tk1E), conceptual question total for Exam 1 (Ex1CqT), and conceptual question total for Exam 2 (Ex2CqT) given during the biotechnology unit. Data also were collected from scores on three conceptual questions related to this unit at the end of semester final exam (Ex3CqT), which was a delayed post-test used as a measure of retention. Only totals on conceptual questions were used in the analyses because for exam 3 the teachers were only able to include conceptual questions on biotechnology. Thus to be consistent, only conceptual question totals for each exam were used.

#### Validity and Reliability

To ensure that the assignments, scoring criteria, and tests accurately reflected the objectives of the biotechnology unit, two science educators and an English educator inspected the dependent variable measures. The conceptual questions were assessed for reliability by computing standardized Cronbach alpha; the internal consistencies were .72 for Exam 1, .73 for Exam 2, and .73 for Exam 3.

Table 4. Description of Dependent Variables in the Order of Data Collection.

Dependent variable	Description
Tk1E	English score on Task 1 (textbook explanation)
Tk1S	Science score on Task 1 (textbook explanation)
Ex1CqT	Total score for three conceptual questions on Exam 1
Ex2CqT	Total score for three conceptual questions on Exam 2
Ex3CqT	Total score for three conceptual questions on Exam 3

Students' scores in the PL group were compared to students' scores in the DPL group. Comparisons also were made between groups regarding the number of writing tasks, scores from the 2WR group compared to scores from the 1WR group.

#### Qualitative Component

Six students from each of the four classes were selected for interviewing. Student selection was partially random as two criteria were used to ensure an even sex and ability distribution between the classes. To achieve a representative distribution, two students, one male and one female from each of the achievement levels of high, middle, and low (based on their baseline entry score) were randomly selected. The 24 students were interviewed after completing Exam 1 and Exam 2. All groups experienced planning, and thus interview questions (see Figure 5) were based on this issue.

1. Normally you just write for Mr. Katts, now you're writing for the 7th graders, was that useful for you? How? Why?
2. Was it easy or hard to do the writing?
3. Was it useful to use the colored wheel template to outline your task?
4. Was the timing when you used the colored wheel template good, or would it have helped you to use it earlier/later?
5. Do you think that the textbook writing added to your understanding of biotechnology?
6. Did you find the group presentations helpful in your understanding of biotechnology?
7. Did the timing of the presentations suit you, or would you have preferred them to be before/after the writing of your first draft?
8. How prepared do you think you were when you were writing your 1st draft?
9. You had 2 teachers comment on your 1st draft, Miss English and Mr. Katts, which did you focus more on, why?
10. Did you change any of your ideas in the redraft?
11. Did you find it useful to do the redraft, did doing it help you understand the topic better?
12. Why do you think we asked you to do the writing assignment?
13. Were you learning as you were writing? How do you think this works?
14. Did this process help you to better understand biotechnology?
15. How confident are you of your understanding having done the textbook writing?

Figure 5. List of questions used as format for semi-structured interviews with Year 10 biotechnology students.

To implement a form of constant comparative analysis (Glaser & Strauss, 1967), each of the interviews was transcribed, with each of the three authors independently reading and coding them for categories related to writing. Coding was based on the core interview questions, that is, categories for coding were the value of planning to assist writing, the role of group work, processes associated with redrafting the writing sample, and the role of writing to a different audience. Each researcher generated a spreadsheet incorporating the number of positive or negative responses and examples for each of the assigned categories. The initial group meeting was held to establish shared understanding of the coding and scoring measurement generated by each researcher such that a reliability of 95% between all

three researchers was reached. At this stage the interviews then were independently reanalyzed to generate a similar spreadsheet for group analysis. At the next group meeting, after examining examples of both confirming and disconfirming evidence, agreement was reached that the four categories were distinct and separate. Initial discussions were held to clarify essential differences between the hypotheses in terms of application rather than at the level of definition. The interviews then were individually reanalyzed to determine if evidence of backward and forward search strategies were identifiable within the categories. The final step was to review the individual analyses as a group to construct evidence, resulting in the generation of assertions described below.

### Pedagogical Strategies

Because this research project was based on examining students' abilities to engage with different types of planning through writing experiences, the teachers' main role was to provide guidance and support for each stage of the process. The writing tasks in this project required students to participate in activities where they constructed and negotiated the meanings of particular concepts for themselves, for a small group of peers, the whole class, and then for younger students, and for those that wrote twice, for the general public. In particular, the teachers expected the students to gain confidence in their own understandings, rather than the teachers playing the usual role of interpretative experts, hence reducing students' effort in constructing meaning. Students' initial requests for concept clarification were directed back to the students' small group support and then other members of the class.

The teachers were keen to ensure that they would help students articulate their own understandings and explain their reasoning strategies, and through discussion explore avenues for gaining a better understanding of the science concepts being reviewed. However,

their function was not viewed as simply providing quick confirmation of correct answers. The teachers constantly reinforced the idea that the students' work and understandings were their own, and that the audience was real and would be provide feedback and critique of the writing samples. Thus the teachers' roles were perceived as providing generic templates, prompting individual student's thinking, providing a range of topics for students to select from, scaffolding students' writing attempts, offering feedback on collected research, clarifying obvious misconceptions, and facilitating small and whole group discussions and presentations.

## Results

The results are reported in two sections to reflect the two components of the study. The first section reports on the quantitative results, while the second reports on the qualitative results.

### Quantitative Results

Adjusted means are reported because analysis of covariance was used. Only significant effects are reported, for  $p \leq .05$  unless otherwise indicated. All test scores, Science and English marks, and baseline scores were converted to percentages. Effect size calculations were performed by converting eta squared values to Cohen d measures using the equation provided by Sheskin (2000, p. 836,  $[d = (\sqrt{4r^2/(1 - r^2)})]$ ). Impact of treatment as determined by Cohen d effect size calculations are: a small effect size for scores ranging from 0.2 to 0.5, medium effect size for scores ranging from 0.5 to 0.8, and large effect size for scores greater than 0.8 (Sheskin, 2000, p. 835).

### Evidence for Planned Pre-writing Experiences

Results comparing planning experiences indicate that students in the PL group scored higher than students with delayed-planned experiences (DPL group) on two dependent variables, English mark for treatment 1 (Tk1E), and Science mark for treatment 1 (Tk1S). Sex was a significant main effect for determining performance on exam 1 conceptual question total.

Task 1 English Score (Tk1E). Significant effects were found for the covariant of base,  $F(1, 63) = 18.43, p < .0001$ , and the main effect of the type of planning experience,  $F(1, 63) = 45.59, p = .021$ , effect size = 0.59. There was no main effect due to sex ( $F(1, 68) = .151, p = .699$ , effect size = 0.09). On the final drafts of the textbook explanation (Task 1), students in the PL group received higher English scores ( $M = 71.24, SD = 16.28$ ) than did students in the DPL group ( $M = 63.13, SD = 16.61$ ). For this model  $MSE = 213.54$ .

Task 1 Science Score (Tk1S). Significant effects were found for the covariant of base,  $F(1, 68) = 17.77, p < .0001$  and the main effect of the type of planning experience,  $F(1, 68) = 4.06, p = .048$ , effect size = 0.49. There was no significant main effect due to sex ( $F(1, 68) = .384, p = .538$ , effect size = 0.16). On the final drafts of the textbook explanation (Task 1), students in the PL group received higher science scores ( $M = 67.58, SD = 15.79$ ) than did students in DPL group ( $M = 58.82, SD = 22.45$ ). For this model  $MSE = 301.73$ .

Exam 1 Conceptual Question Total (ExCqT). Significant effects were found for the covariant of base,  $F(1, 68) = 15.55, p < .0001$  and the main effect of sex,  $F(1, 68) = 9.03, p = .004$ , effect size = 0.73. There was no significant main effect of treatment on student performance for conceptual question total,  $F(1, 68) = 2.24, p = .139$ , effect size = 0.36. Males achieved significantly higher scores ( $M = 61.14, SD = 22.41$ ) than females ( $M =$

48.33, SD = 21.15) on the conceptual question total for Exam 1. For this model MSE = 396.08.

#### Evidence for Multiple Writing Experiences

We conducted a 2 x 2 analysis of covariance to determine the effect of planning and sex on performance on conceptual question total score for Exam 2 when controlling for base. Results indicated that there was no significant difference between the planned and delayed groups in terms of performance on Exam 2 conceptual question total ( $F(1, 28) = 1.811$ ,  $p = .189$ , effect size = 0.51). Neither sex ( $F(1, 28) = .699$ ,  $p = .410$ , effect size = 0.31) nor treatment had a significant main effect on the conceptual question total score for Exam 2. Thus, we conducted a second 2 x 2 analysis of covariance to determine the effect of a second writing treatment (that is, planned and delayed planned students as a single group) and sex on performance on the Exam 2 conceptual question total controlling for base. The same 2 x 2 analysis of covariance was conducted to determine the effect of writing and sex on performance on conceptual question total for Exam 3. The difference detected on Exam 2 conceptual question total persisted when total scores for conceptual questions were analyzed for Exam 3.

Exam 2 Conceptual Question Total (Ex2CqT). There were significant effects found for the covariant of base,  $F(1, 66) = 17.20$ ,  $p < .0001$ , and the main effect of the number of writing experiences  $F(1, 66) = 8.139$ ,  $p = .006$ , effect size = 0.70. Sex did not have a significant main effect in determining performance,  $F(1, 66) = 2.75$ ,  $p = .102$ , effect size = 0.4. Interaction between sex and writing treatments was not significant  $F(1, 66) = 0.263$ ,  $p = .610$ , effect size = 0.13. Results indicate that students in the 2WR group scored significantly higher (M = 77.73, SD = 16.87) than students in the 1WR group (M = 62.13, SD = 23.09) on Exam

2 conceptual questions with the second writing treatment having a medium effect on performance. For this model  $MSE = 336.31$ .

Exam 3 Conceptual Question Total (Ex3CqT). We found significant effects for the covariant of base,  $F(1, 68) = 26.69, p < .0001$  and the main effect of the number of writing experiences,  $F(1, 68) = 20.139, p < .0001$ , effect size = 1.09. Sex did not have a significant main effect in determining performance,  $F(1, 68) = .084, p = .773$ , effect size = 0.06. Interaction between sex and writing treatments was not significant  $F(1, 68) = 0.069, p = .794$ , effect size = 0.06. Students in the 2WR group scored significantly higher ( $M = 70.83, SD = 16.31$ ) than students in the 1WR group ( $M = 49.45, SD = 21.60$ ). Results from exam measures indicate that students in the 2WR group scored significantly higher on the conceptual question total for the delayed post-test Exam 3 regardless of sex. The second writing had a large effect on performance on conceptual question total for exam 3. For this model  $MSE = 277.13$ .

### Qualitative Results

In analyzing patterns in students' perspectives on how they tackled this writing task and the effects of this process on their learning, we have grouped their responses into the following four assertions: the general value of the planning experiences in tackling the task; the importance of discussion as part of planning and learning processes; the effects of different task requirements on text generation and revision strategies; and the value of a translation task for student learning. Student data is reported in a manner to indicate whether the student was in the PL or DPL group, and whether for the purposes of research they were classified as in the high achieving group (H), the middle achieving group (M), or the low achieving group (L).



Assertion 1. The planning support enabled students to understand and complete the writing task. Students perceived that full writing support, including small- and whole-group discussion, and peer and teacher feedback, enabled effective task completion for both the PL and DPL groups. However, the timing of this planning influenced students' perceptions of their preparedness in drafting their writing; 58% of the PL group said that they were prepared adequately to complete the writing task compared to 25% for the DPL group. For example, Corey (PL, H) said, "We had all the information. I was totally prepared" as opposed to Amelia (DPL, M), who said, "I think the first draft was really hard...I didn't know what I was doing." The planning process was viewed as valuable because "it helped to organize it [the writing]" (Jeremy, PL, L), as another student explains, "[because] once I used the wheel [template] before I researched I think it helped because that way I knew exactly what portions of the research I really needed" (Karen, PL, H). This confidence in understanding the task was not expressed by those in the delayed planned group. For example, Sherry (DPL, H) stated, "I didn't really understand exactly what I had to write. I didn't understand that I had to put in so much detail", and Christina (DPL, L) explained, "you don't know what order to put it in and stuff like that...[I was] not very prepared at all. I mean I didn't know anything about it." The planning sessions for the DPL group enabled them to go "back over it [the first draft] and kind [of have an] overview. We looked at all those questions and actually saw what to look at and improve" (Harry, DPL, M). While nearly all the students welcomed the planning opportunities, Jacqueline (DPL, L) was an exception, claiming writing does not require planning "because I don't outline the writing. I just kind of write; then I go over it. I really didn't find it [the planning sessions] all that useful."

When asked to comment on the timing of the presentation to the whole class, 92% of the students in each class stated that the timing was appropriate. The opportunity to present and receive feedback from the class as whole was seen as valuable. However, students in the DPL group indicated that they presented their first drafts for their class presentation and that “everyone could help each other out to make it better, since we already wrote it. It helped us to make it better, make sure it was understandable” (Sherry, DPL, H). The support from each other as a consequence of the presentation for the DPL students is reflected in Kevin’s (DPL, H) comments:

Yes because I had the chance to see what other groups were doing and how they explained stuff. They kind of put it into simpler terms than I did and that made me change mine so I could explain it better and so I could understand it better. They had little bits and pieces just like I did and I put the whole big picture together with the group.

For the PL group, the presentations enabled students to determine the amount of information that they had collected or needed to collect. For example, Corey (PL, H) responded that “it helped us think more and get more information so that we could make our papers better, so we could put more information on there.” This feedback gave students “more options with what to do and what you needed to work on” (Betty, PL, H), or revealed that other students had “found something that you didn’t and you could write something down” (John, PL, L).

The difference in focus between the PL and DPL groups for the presentations appeared to be centered on information gathering (PL) versus explanation (DPL). The DPL students had their “first drafts done and used those to make the presentations” (Jacqueline DPL, L) while the PL students were preparing to write their first drafts. In spite of this difference, both groups were aware of the value of planning for completing the written task,

even when each group had experienced a different sequence of writing and planning opportunities.

Assertion 2. Negotiation of meaning through discussion was perceived by the students as a critical component of an effective planning process. All of the interviewed students in both groups indicated that working within their small groups was helpful in constructing understanding. The focus of these negotiations was predominantly around either the information required in the writing or the appropriateness of language required for the younger audience. Using negotiation to construct meaning was perceived to be useful not only “because you all share your ideas and it makes it easier” (Christina, DPL, L), but (also) because there were opportunities so “if you didn’t catch something, someone else caught it” (Kelsie, PL, L). As Jacqueline (DPL, L) pointed out “if you have somebody else who is doing the same thing, then you can kind of get some of their information and compare it. See how you did” and this helped generate confidence in understanding because “you just knew” (Kelsie, PL, L) what was supposed to be put into the paper. Students viewed their constructed knowledge as resulting from more than just their own thoughts, rather as a mixture of their own ideas and the group’s responses to their ideas. As Karen (PL, H) said,

When we all got together and discussed this research “how does it relate to yours,” then when people would bring up these different topics there is kind of that point where somebody would say “no that’s not right or that’s not what I think” but they figured out a way to word it so it combined the two into the paper.

This opportunity to add to one’s own knowledge was viewed by Jeremy (PL, L) as really important for his learning because

Discussing it helps me a lot. That is one of the main things that helps me.  
By writing it down and reading it, it helps but not as much as discussing

it because you can get everyone's opinions, and put your own in too, and see if you are right about it.

The value of the negotiation process was not just having the information correct, but (also) having the opportunity to review feedback concerning the level of language used for the Year 7 audience. By discussing their ideas within the group students were able to understand that "we just needed to put it in easier words" because "if they [the group] didn't understand it, I knew I had to go back to my paper and change it" (Sherry, DPL, H). In responding to the group's suggestions, students were able to complete what they perceived to be a better product. As Jeremy (PL, L) pointed out,

Some people said to change the wording, so I did that. I used smaller words so that they could understand what I was talking about. And I lengthened paragraphs since I had added stuff, and took some stuff out. [I] sorted it out and made it better.

The verbal negotiation of meaning through group work and feedback was perceived by students as crucial to developing their understanding of the topic and enabling them to plan and complete the writing task successfully. This perspective is consistent with sociocultural frameworks for understanding learning in science, where knowledge is understood as distributed across groups rather than residing in individuals, and where the group work provides a purposeful social context for learning.

Assertion 3. Students in the PL group were engaged in more backward searching than DPL students when redrafting their writing. Analysis of the interviews indicated that there were differences in the actions taken during redrafting between the DPL and the PL group. Students in the DPL group predominately referred to the need to add more words of explanation, that is, they did not feel as though their first draft was adequate in terms of the explanation provided. For Amelia (DPL, M) there was a need to add more because

The first one I didn't know what I was doing. I was just writing stuff down. On the second one, I think it helped me understand a lot more because I realized that I didn't put enough information into the first one and I wouldn't even have understood it if I was a 7<sup>th</sup> grader reading it. So I went back and did a better job on it.

The concept of having to add more information was explained by Mike (DPL, M) who described initially writing at the "surface" of the subject, "I didn't get too in-depth in the first one. I kind of just hit the surface slightly. On the second draft I kind of got into it." Kevin (DPL, H) further expanded on this point, "I just needed to elaborate more and continue on with my ideas. I wasn't expressing enough." The greatest change in completing the task was by Kylie (DPL, H) who "changed my whole paper."

Students in the PL group constantly referred to the opportunity to re-order their ideas when completing their second draft. Not only did they state that they re-worded their ideas to deal with the needs of their audience, but they were also able to make better links between the ideas and thus construct a better sense of an organized conceptual framework for the topic. In this way they were participating in backward searching. For Claire (PL, M) it was a matter of getting "the sections and stuff organized better so it is easier to understand. There is one section about something and the next section will be about something, so that you don't mix it all together. It is all like separately organized." The redraft process enabled these students to organize their understandings into a more coherent and connected set of ideas. As Betty (PL, H) said

You have to be organized. You have...I mean you can't write about something else and then explain it like further down on the page or tell about something and not tell what it means. You have to make sure you are going in the right direction with it so they understand what you are talking about through the whole paper.

Students found the opportunity to read other students' work insightful because the drafts "aren't really well written and [the authors] kind of ramble on, and I don't think that it is really easy to understand" (John, PL, L). This helped guide students like John (PL, L) because as he said "I think you have to separate things into each other and then get them inter-related and switch off [stop rambling]. That helps me understand better." By contrast, the DPL group tended to focus on the goals of the task or conceptual explanations rather than an extended focus on the organization of concepts or finding relationships between them.

The DPL group did not refer to the organization of their concepts in the manner in which the PL group did. These students tended to be at the stage of assertion 2, in that they were still dealing with goals of the tasks and conceptual explanations. The PL group were focused on the relationship between the concepts and how best to represent these, and thus were engaged in a deeper form of forward searching. Importantly, students' comments indicated that the timing of the planning experience had a strong influence on the kinds of goals or purposes addressed in the generation and revision of their texts.

Assertion 4: Students understood that a translation of scientific language into a more accessible language for the younger audience was required, and that this translation assisted their understanding of the topic. Most students (85%) indicated that when writing for the teacher they used "big words" or technical language, which they did not always understand. Writing to "Mr. Katts [the teacher] ... you don't really have to simplify it all. He can pretty much pick it up and understand a lot of what you write" (Kevin, DPL, H), thus perceiving the teacher as an interpretive expert. Students realized the distinction between writing for the teacher and writing for a younger audience, "Mr. Katts expects you to write more and in bigger terms than what you would write for 7<sup>th</sup> graders" (Christina, DPL, L). In writing for

the audience, they indicated that they had to change the words to make them *simpler* [italics added] so that the year 7 students could understand them. The concept of making things simpler was so “that 7<sup>th</sup> graders would understand it better” (Travis, DPL, L) and this was clearly different to the normal situation when “usually we just take what Mr. Katts says and put it in our brain just like he taught us” (Betty, PL, H).

The process of translating language involved students in both backward and forward searching, greatly assisting their construction of understanding. In this way, writing is both a scaffolding agent for learning and a socio-cognitive process that links group and individual understandings. Sensing the need to translate science language into one that was meaningful for the audience involved backward searches; and by writing to achieve that goal, students were constructing understanding. For example, Jeremy (PL, L)

used smaller words so that they [7<sup>th</sup> graders] could understand it better instead of writing something that was impossible for them to understand. I didn't exactly understand some of the stuff either. So by writing some of the wording down I understood it better.

Students referred to the notion that “once you take it and read it and try to put it in younger kids' points of view, then it helps your mind actually think about it and understand it”

(Kelsie, PL, L). Students not only had to write so that they could understand the concepts but they also had to make “it easier for everyone to understand” (Mindy, DPL, M). For John (PL, L) the process involved

figuring out how to dumb it down, it helps you try to find out what it really is...just thinking about how they would understand things, and then if you think they would understand it, then there is a really good chance that you would understand it.

While some students approached the task by simply writing the textbook explanation “like I normally would for Katts and [then] I went back through and changed all the large words”

(Paul, PL, H), others understood that a richer explanation was required. For example, Jeremy's (PL, L) process was more involved

If it is a big word you have to use, like biotech regulations, you have to explain what that was. Like you have to explain what bio means, what technology means, and [what] regulations means because they don't exactly know what that is. You can't really reword it so you have to explain what every little part of that means.

Similarly, Harry (DPL) described the process of translating the language, "first you dumb it down, learn that, and get the basics down really well, and then you can move onto your large textbook definitions." The value of having to explain the terms in their own language was seen as beneficial as "that helps you understand more" (Kylie, DPL, H) because "if it is in simpler terms it is easy to comprehend" (Jacqueline, DPL, L). The recognition that writing to an audience different from the teacher caused them to use different language, which promoted learning is summed up by Amelia (DPL, M) who said, "I think that made me learn the most, writing to seventh graders because I actually found out what it meant. If I would not have done that, I would have just written down all those big words."

The elements of forward searching are related to the concept that in the process of generating new text, the writer is generating new meaning. While the majority of students' shared this view, 25% of the students described some elements of constructing meaning as they wrote their text. For example, Kevin (DPL, H) explained that in breaking the words down "you actually get to see what they mean" and described the process he used as one in which "you see different parts and all the same parts but different words, that way you can piece together what they mean". This process was not a simple one and involved many iterations, "because I would write it down and someone would be confused because I know what I'm saying [but] nobody else does. I had to rewrite it many many times to get it right"



(Tammy, PL, M). While Paul (PL, H) described backward search elements, he also indicated the use of forward search elements “as you write it out you have to make it into sentences that you understand and that really works.” This writing was viewed as different from the typical writing tasks in that “like study guides, sometimes you look for the shortest answer that will just fill the question and this one we actually had to write it for other people to understand” (Paul, PL, H). For Betty (PL, H) the process required her to continually cycle through a thinking process because

you have to think about what you are going to say and how it all fits into the sentence or the paragraph or whatever it is, and you have to kind of put it all through your mind again before you write it down on paper.

Although the students viewed the language used as being simple, the process was viewed as complex. For example, Jerad (PL, M) stated, “I think you are still writing in a complex form but not [using] complicated words that no one knew about.” As a consequence Jerad (PL, M) originally “wrote this twelve word paragraph that turned into a page long thing” and in doing so he acknowledged the necessity of expanding his explanation to meet the needs of a younger audience.

Students in both the PL and DPL groups indicated that they perceived gains to their learning when they were required to change technical explanations and vocabulary into simpler terms for younger readers. The student comments indicate recognition of the value of this kind of translation task for consolidating their learning, independent of whether they were in the PL or DPL groups.

### Discussion

The results of the study indicate that the use of nontraditional writing activities incorporating planning, either initially or delayed, was beneficial in helping students

performance on answering conceptual questions in test situations. In recognising the limitations of the sample size and its effect on potential confidence in results, the study does none-the-less highlight an important trend when comparing the changing effect size scores across the study for sex and treatment. The effect size for sex decreased from 0.73 (medium effect) for conceptual question total for Exam 1, to 0.13 (small effect) for conceptual question total for Exam 2, to 0.06 (no effect) for conceptual question total for Exam 3. The opposite trend for the treatment was noted. The effect size for the first writing treatment (planned vs. delayed planned) for conceptual question total for Exam 1 was 0.36 (small effect). There was only a small effect for planning on performance on conceptual question total for Exam 1. In collapsing all the students who wrote twice, regardless of being either planned or delayed planned, the results indicate that the effect size for performance on conceptual question total for Exam 2 had increased to 0.70; that is, the impact for a second writing treatment had increased over that for a single writing treatment. When the analysis for conceptual question total for Exam 3 was done, the effect size for those who had written twice compared to a single writing treatment, had increased to 1.09, that is, the second writing treatment had a large effect on student performance on conceptual questions on Exam 3. From a statistical perspective, the results were very positive. The impact of non-traditional writing activities on performance on conceptual questions increased over time when students had multiple experiences, while the difference in performance between males and females decreased to be almost negligible.

Students' comments support and highlight the value of these activities, as evident in our first assertion about the perceived value of planning, as well as in our second assertion about the perceived value of discussion to consolidate emerging understandings. These

student perceptions concur with recent research findings by Rivard and Straw (2000) about the value of integrating exploratory student discussion with writing tasks in order to clarify student understandings.

However, in examining the students' comments the researchers would point out they are specific to engagement with one set of writing tasks under particular classroom conditions as outlined, and should be viewed with some caution in terms of generalized application to all writing tasks. Given this constraint, the students' comments on their practices and perceptions as they sought to clarify concepts and address writing tasks demands provide some evidential support for the value and effectiveness of forward and backward search hypotheses for learning through writing, as outlined by Klein (1999). While some past studies have assumed that there is an automatic value for learning in forward and backward searching by writers as they develop or revise a text, this study provides some justification for this assumption, particularly in relation to this task. The forward search, or the initial generation of text to clarify understanding of key concepts, was evident as students attempted to respond to the task's global purpose, namely the production of an informative piece of writing for younger readers. Most students perceived this goal as valuable for guiding their subsequent focus, selection, and clarification of concepts for learning about biotechnology. This global goal, resulting in a focus on relevant content and procedural goals, enabled the students to make informed judgments about the clarity and progress of their understanding through writing and rewriting. As further indicated by their comments, the ongoing production of their texts enabled them to refine and organize their understanding of the topic, and hence their comments support the forward search hypothesis as a convincing account of how writing in this particular instance served learning.

The students' comments also indicate the value and effectiveness of backward searching, or the subsequent process of revising textual meaning to enhance communicative goals and to clarify meaning further for self and others. As the students noted, this writing served their learning by extending their conceptual framework on the topic as they varied the language they used to explain and integrate concepts for self and others. Most students perceived that they had to find wording to explain the concepts to themselves before they could explain them to readers. For many students this requirement provided an effective new scaffolding technique for their learning. The students' comments indicate that their conceptual framework was enriched by these attempts to negotiate the meaning of concepts in different communicative contexts, incorporating technical and everyday language. By providing a real audience with needs the students recognized, the writing task gave students effective ways to assess the relative success of their attempts to explain relevant concepts.

Analysis of the qualitative data further suggests that the nature of the task, and the timing of planning in tackling the task, further influence the purposes and kinds of revisions students undertake. As noted in the assertions, students in the PL group reported the use of more backward searching to address task demands than students in the DPL group. In other words, the timing of planning may have an effect on how students conceptualize task success and which strategies they use to complete the writing. This suggests a possible link between the design of the instructional program in terms of the timing of planning and revision opportunities, the kinds of redrafting purposes undertaken, and conceptual gains for the students. In this regard this study concurs with Klein's (2000) recent findings that increased demands in revision purposes and practices, entailed in backward as well as forward searching to redraft a text, may yield enhanced learning outcomes when compared to

predominantly forward search strategies. As already indicated, forward and backward student searching of texts may overlap, depending on writer perceptions and intentions. However, this study suggests that extended opportunities to revise and clarify the wording and organization of a text for self and others can produce enhanced learning outcomes.

As the students' commentaries also made clear, various planning experiences all contributed to their learning, not just the act of writing a text. Clearly, for some students parts or all of their written drafts were perceived as a record of prior knowledge or resolved understandings from other activities. However, the students also generally believed that their emerging text provided a clear basis for self-evaluation of their understanding and enabled them to consolidate and organize further their knowledge of key concepts, as well as relationships between concepts. While this particular task and classroom program encouraged students to adopt the specific cognitive strategies evident in their responses, it seems reasonable to suggest that addressing a meaningful global communicative goal in other writing tasks might also lead to students using similar cognitive strategies.

This research project also incorporated teacher-devised generic templates to guide students' structuring of their writing. Students found these supports useful in organizing ideas, and hence their comments provide some further support for the validity of genre-based theories of how writing serves learning. However, these templates did not specify micro structural linguistic features for students to incorporate into their drafts. The researchers assumed that there was value in not pre-empting students' own options in how they organized their textbook explanations or newspaper articles, or perceived the relationships between key ideas. While less able students benefited from explicit teacher-led scaffolding of text structures, others devised their own structures for the writing task. These structures varied in

the extent to which students integrated concepts or represented them as separate. This pattern of responses supports Klein's contention that the genre-based hypothesis provides only part of an answer to the question of how writing serves learning. The cognitive factors influencing student choices in how they link, or separate, concepts within a textbook or newspaper genre are a further issue. In other words, knowledge of generic frames can certainly enable students to display their knowledge more cogently, but these frames do not, on their own, facilitate learning. The students still need to know how to negotiate each aspect of the genre's demands in relation to their knowledge of the concepts, and such a negotiation is likely to be based upon forward and backward searching for textual coherence and evidence of meeting reader needs. This self-regulatory knowledge, as noted by Bereiter and Scardamalia (1993), is personal self-knowledge about how to perform in a certain domain, and is different from domain knowledge, such as knowledge about generic structures. Explicit instruction on textual macro and microstructures can address the second kind of knowledge, but the first kind is developed through students' understanding how and why to carry out forward and backward search of their texts. This suggests that the use of templates, and their degree of specificity, should be based on the teachers' awareness of class needs and capacities, but should not be seen as the major or only way in which writing can serve learning.

This study also found that students who participated in more than one non-traditional writing task achieved further learning gains on conceptual questions when compared with students who completed only one writing task. Students who wrote once completed traditional tasks involving the same content, thus ensuring that time on task in terms of learning subject matter was equal for all students. This improved performance among students completing two writing tasks raises the issue of the possible cumulative learning

benefits from different linked, writing tasks. This highlights the further issues of which tasks, and which task sequences, maximize learning gains. While the quantitative component of the study indicated that there were significant learning gains from students undertaking an additional, linked writing task, there is the need for further research to address the question of which linked writing tasks, task sequences, and number of tasks will optimise learning opportunities for students.

The students' comments also confirm other research findings (Chinn & Hilgers, 2000; Keys, 1999; Kelly & Chen, 1999; Prain & Hand, 1996) that claim certain aspects of task design and particular classroom conditions are likely to promote learning through writing. The writing tasks should entail meaningful audiences for whom student writers recognize task demands and have strategies to address these demands. This study confirms Sutton's (1992) claim that tasks, which require students to expand, simplify, and elaborate their emerging understandings for real readerships, are likely to enable students to consolidate conceptual knowledge in the process of writing. This translation activity, as noted by Lemke (1990) and as the students' comments confirm, encourages the students to build richer linguistic networks for the topic's target concepts than occur when concepts are represented only in 'authorized' scientific vocabulary. As their responses indicated, students perceived that this task required them to clarify concepts for themselves to explain them to others, and that this process focused and enhanced their learning. The students' comments also confirm Chinn and Hilgers' (2000) claim that students learn from writing where there are frequent verbal and written interaction between student and teacher, participation in a collaborative learning community, clear guidelines for writing, and opportunities to write for other audiences. In other words, as noted by Lave and Wenger (1991), classroom conditions serve

learning when there is a range of meaningful communicative practices that support students in all stages of writing, including feedback on their initial and advanced efforts.

### Implications

This study, building on our research program to date, also indicates important conditions that need to be met for writing to serve learning: (a) Writing tasks should be designed that require students to focus on conceptual understanding, and also require students to elaborate and justify these understandings of the topic; (b) the target readership should be meaningful for the students to give the task a strong sense of authentic communicative purpose; (c) students also should be provided with sufficient planning support, although such support should not preempt student initiative and sense of engagement with, and ownership of, the task; and (d) planning activities should engage students in purposeful backward and forward search of their emerging texts.

This study has implications for current theories of how writing serves learning and for future research in this field. The study suggests that backward and forward search theories, linked to a focus on the micro and macro features of genres, can be integrated to provide a plausible framework for interpreting how writing served learning for students in relation to this specific writing task. However, there is a need for further research on different kinds of tasks and diverse student groups using different planning and composing strategies to identify whether this theoretical account is supported by contrasting practices.

There is also a need for further research into different task sequences to identify practices that provide the most gains in cumulative learning benefits. In devising this kind of sequence clearly there are issues of plateau effect and student tolerance of sustained writing. For these reasons, this kind of linked writing sequence should be used to clarify only more



demanding conceptual understandings that will benefit from this sustained effort, and such a sequence should entail revision without perceived sense of excessive repetition for students.

## CHAPTER 4. WRITING-TO-LEARN STRATEGIES IN SECONDARY SCHOOL CELL BIOLOGY: TWO PARALLEL MIXED METHOD STUDIES

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### Abstract

While there is some evidence that writing-to-learn techniques support learning, a need remains for more empirical research describing the instructional context used to support learning through writing as well as the quality of learning that may result from engaging in particular writing tasks. This paper builds on past research linking inquiry, social negotiation, and writing strategies to student learning assessed for recall and conceptual understanding. In two parallel studies, all participants conducted the same guided-inquiry labs and completed two different types of writing consisting of 1) a series of 6 laboratory reports and 2) a final summary report. Three comparison groups were used, Control group students completed laboratory reports using a traditional format, while students in the SWH group used a modified template, the Science Writing Heuristic (SWH). Control group students completed a summary report directed to the teacher, while students in the SWH group wrote summary reports either to the teacher or to an audience of their peers (Peer Review group). Assessments were administered following both writing types. Quantitative results indicated SWH females performed better after laboratory writing compared to SWH males and Control females; and as a group SWH students performed better than Control group students on the test administered after summary report writing (Study 1). These results were not replicated in Study 2 and potential reasons are discussed. An open-ended survey revealed findings that persisted in both studies; SWH students described learning as they

were writing and were more likely to report distinct thinking was required in completing the two writing types compared to Control group students.

### Introduction

Scholars working within the writing-to-learn movement point to the strengths inherent in the use of language that may create, describe, and reflect existing ideas and understandings (Halliday & Martin, 1993; Hand, Prain, Lawrence & Yore; Keys, 1999b; Lemke, 1990; Roth & Roychoudhury, 1992). For the writer, the act of writing requires thinking, offers opportunities for reflection on content, promotes attainment of personal meaning, and furthers the development of processing skills such as organizing ideas and reasoning (Applebee, 1984; Bereiter & Scardamalia, 1987; Fellows, 1994; Rivard 1994; Rivard & Straw, 2000, Rowell, 1997). In writing, a student can demonstrate significant effort and communicate understanding of scientific content. Writing is a means for supporting conceptual change, facilitating and documenting the degree to which conceptual change occurs, and providing one basis for further modification of instructional interventions (Fellows, 1994; Hand, Prain, & Wallace, 2002; Rivard & Straw, 2000). When writers employ successful strategies they become "more aware of language usage, demonstrate better understanding and better recall, and show more complex thinking about content" (Rivard 1994, p. 975).

While recent studies have identified learning gains, such as improved performance on conceptual questions after exposure to writing tasks (Hand, Prain, & Wallace, 2002), in general, pragmatic applications have yet to maximize these learning enhancing potentials. Instead, the status quo of lecture-based or didactic instruction (Mullis & Jenkins, 1988) appears to remain. Students are typically asked to provide short phrase responses to lower-

level cognitive questions, requiring little synthesis, and writing tends to be directed to one audience that primarily consists of the teacher (Applebee, 1984b; Fellows, 1994; Holliday, Yore, & Alverman, 1994; Klein, 1999; Rivard 1994; Rowell, 1997).

There is general agreement that language plays an essential role in understanding principles and concepts of science, although "an emphasis on the role of language as a medium of communication might actually block its generative function" (Rowell, 1997, p. 40). Rowell suggests, for example, that when students perceive writing in science classes as simple summary of essentially factual information (Moje, 1995), this can lead to erroneous assumptions or a limited view about the nature of science. These beliefs likely interfere with processes designed to use language to facilitate meaning making and knowledge transformation. Lemke (1990) noted compounding problems in science instruction, which generally lack support for students in negotiating meanings of scientific language. Students are not generally taught "how to speak, argue, analyze, or write science" and instead teachers tend to make meaningful relationships explicit only at the beginning or closing of the topic (Lemke, 1990, p. 22).

Although it is recognized that writing can serve learning in a variety of ways, these benefits are not considered to automatically follow an isolated act of writing (Rowell, 1997; Ackerman, 1993). Researchers recognize certain problems remain in that results from a limited number of studies designed to determine the effect of writing strategies on learning have been inconsistent and the links between writing and thinking have been largely assumptive (Applebee, 1984; Klein, 1999; Rivard, 1994). Evidence from classroom studies of writing strategies used to transform knowledge is limited and requires more description of the "pedagogical context" in which writing takes place (Rowell, 1997, p. 35). Additional

empirical research is needed with target populations of students in middle and secondary schools to clarify links between writing, critical thinking, reasoning, and conceptual change, and to explore mechanisms for maximizing learning through writing (Applebee, 1984; Klein, 2000; Rivard, 1994; Rowell, 1997). While the general problems identified over the past two decades appear to remain, a sustained effort has led to a body of research that, while relatively small, highlight difficulties students encounter and point to important connections between theory and practice.

Breakthroughs, barriers and promises from the writing-to-learn movement and writing for learning in science have been extensively reviewed elsewhere (Holliday, Yore, & Alvermann, 1994; Yore, Bisanz, & Hand, 2003; Ackerman, 1993; Rowell, 1997; Rivard, 1994; Klein, 1999). Thus, only a sampling of a few recent studies highlighting the challenges students face in the act of writing are presented here as they provide focus for instructional programs and goals for research, particularly pertinent to the present investigation. These studies utilizing writing as part of the instructional sequence have been conducted at various classroom levels, elementary (Duschl & Ellenbogen, 2002; Mason, 1998), middle-school (Fellows, 1994; Keys, 1999b), and high school (Hand, Prain, & Keys, 2002; Rivard & Straw, 2000).

Duschl & Ellenbogen (2002) analyzed discussions of elementary students using the computer program, Knowledge Forum. Working in groups with graphs of collected data, these students were to determine a range for normal resting heart rate and identify the best representative graph(s). While several laboratory groups had used mathematical calculations in formulating "decision rules" when determining ranges in their laboratory notebooks, students failed to identify the best graphs and did not include, to a large extent, their rules for

decision making as supportive evidence in electronic submissions. The researchers indicated that further instruction could "benefit from a consideration of the argumentation steps needed to move from raw data to polished explanations" (p. 11). To this end, they recommended modifying directions and including scaffolding prompts to guide students in providing explicit statements of reasoning and evidence used in decision-making, which could improve discussion contributions and support development of scientific arguments. Similar challenges were found with middle school students during a molecules and matter unit, as students had some difficulty providing written descriptions of their reasons for thinking differently about physical change (Fellows, 1994).

Other challenges occur when using writing to stimulate thinking that results in persistent conceptual change. Student learning tends to involve memorization of terms without changing thinking, "when they are asked to describe, explain, or make predictions about real-world phenomena, students find their memorized facts and algorithms useless and return to their familiar real-world conceptions" (Fellows, 1994, p. 986; McCloskey, 1983). However, Fellows (1994) found that instructional activities including discussion and reflective writing led to conceptual change. Students added new concepts and theories to their writing and improved the logical organization of arguments in their explanations, which were more in line with those accepted by the scientific community. In a study with fifth-grade students, Mason (1998) found more than half (62%) of students' post-discussion writings were reflective, in which students described changing their initial conceptions from those they had prior to discussion. Interviewed students attributed the development of their scientific explanations to the collaborative reasoning they experienced during discussions.

As part of a summer program for middle schools students, Keys (1999b) analyzed both individual and collaboratively written reports on topics of water quality and zoo animal behavior, respectively. She found benefit for some students in that their texts served as a medium for conducting aspects of scientific inquiry such as forming inferences from data, developing explanations, and composing new hypotheses. However, a majority of students' reports lacked evidence of new meanings generated from data and analyses indicated that many students had problems directly relating "their observations to new hypotheses or knowledge claims" (1999b, p. 1057). Keys emphasized that these students were not provided full writing support as part of the program. In an earlier study (Keys, 1994) with year nine students in the context of the classroom, scaffolding of report guidelines was provided; these students participated in collaborative discussions and wrote reports together in pairs. In six focus students' reports, Keys found improvement in summarizing relevant information from the textbook, using data and observation, and greater clarity in comparing and contrasting explanations. Insights from the studies above as well as the literature reviews indicate students need full writing strategy support (Klein, 1999; Yore, Bisanz, & Hand, 2003) through teacher scaffolding (Rowell, 1997; Patterson, 2001). Both opportunities to discuss ideas and guidance in planning during portions of the writing process appear to be important pedagogical components to facilitate learning through writing (Hand, Prain, & Hohenshell, 2002).

### Theoretical Background

For writing to be a successful learning tool leading to knowledge transformation, strategies should be embedded in an interactive constructivist approach to learning (Yore, Bisanz, & Hand, 2003) during which students have opportunities for social negotiation of

language use through collaborative discussion and argumentation (Rowell, 1997). The interactive-constructivist perspective accepts both individual and social aspects of learning science in recognizing that the personal responsibility of knowledge construction is facilitated by social interactions (Yore & Shymansky, 1991); similar approaches are also advocated by literacy educators (Dixon-Krauss, 1996). A concise summary of an assertion made by Harste (1990) "most of what a person knows about language is learned in the presence of others through use" (Dixon-Krauss, 1996, p. 8), concurrently emphasizes the fundamental point that "communication...is always a social process" (Lemke, 1990, p. x).

Linking the practices of discussion and writing to theories, Rivard and Straw (2000) explain, "the use of writing as an instrument for learning underlies the personal construction of knowledge, whereas the use of talk for learning is consistent with social constructivist thought" (p. 569). Rowell (1997) also connected theories to writing in science in aligning perspectives from cognitive psychology and Vygotsky's socio-historical theory,

cognition is interpersonal before it is intrapersonal; thus, the construction of meaning (learning) is influenced to a large extent by the social and interactional experiences in which language is developed. And so, while the act of writing is frequently an individual act, what we write and how we write is shaped by the language of the community around us. (p. 23).

What becomes clear then in terms of science literacy, is that students need opportunities "to use language, think and act in ways that enable one to be identified as a member of the scientific literate community and participate in the activities of that community" (Wallace & Narayan, 2002, p. 4). Duschl & Ellenbogen (2002) explain, "to discuss, evaluate, and debate the processes, contexts, and products of inquiry expose the members of the community to each other's ideas, opinions, sources of evidence, and reasoning" (p. 4). Key components of



classroom practices that provide such opportunities reside in discussion, collaborative discourse, and argumentation.

#### Collaborative Discourse and Argumentation

Several researchers (Fellows, 1994; Keys, 1994, 1999b; Prain & Hand, 1999; Rivard & Straw, 2000) have illustrated the supportive role of writing in promoting conceptual change, particularly when used in an environment encouraging collaborative discourse. In the context of ecological problem solving activities, Rivard and Straw (2000) compared four student groupings, individuals completing traditional tasks, peers discussing, individuals writing, and a combined group of peer discussion and individual writing. They found that discussion and writing together were more important than either individually completed tasks for performance on both simple and integrated multiple choice test items. Sex interactions from analysis of simple recall measures indicated that this combination was particularly important for boys and that girls benefited more from peer discussion compared to writing alone. These results further emphasize the need to combine discussion and writing; they also point to a potential relationship between sex and the benefits gained from particular learning strategies.

Rivard and Straw (2000) indicated the value of discussion, which "appears to be important for sharing, clarifying, and distributing knowledge among peers. Asking questions, hypothesizing, explaining, and formulating ideas together all appear to be important mechanisms during these discussions" (p.585). Fellows also surmised the role of talking in meaning-making and of both talking and writing as mechanisms "for stimulating the reflection and feedback that facilitates knowledge changes" (1994, p. 999). Comparing written responses and peer discussions, Rivard and Straw (2000) explained the distinction

lies in each task's requirements, "oral discourse is divergent, highly flexible, and requires little effort of participants while they collectively explore ideas, but written discourse is convergent, more focused, and places greater cognitive demands on the writer" (p.583).

A related activity, argumentation, is a form of discussion that focuses on claims and analysis of supportive evidence. Argumentation has been described as "a genre of discourse and an epistemological framework central to doing science" (Duschl & Ellenbogen, 2002, p. 2). Clarifying scientific thinking skills as they relate to the practice of argumentation, Wellington & Osborne (2001) explain that learning to reason in science "requires the ability to use the ideas and language of science... [and also] requires the ability to begin constructing arguments that link evidence and empirical data to ideas and theories" (p. 83). Through argument, students individually construct knowledge from interactions with teachers and peers. Through these social negotiations, students address their prior knowledge, may face disequilibrium, and experience conceptual change (Driver et al., 1994). Lemke argues that "talking science" is not only "talking about science. It means doing science through the medium of language" (1990, p. ix). Kuhn (1993) expanded this notion as it relates to discursive practices of science, explaining that when "...ideas are articulated, questioned, clarified, defended, elaborated, and indeed often arise in the first place," (p. 321) students experience science. Support through the use of scaffolding discourse, argumentation (Driver et al., 1994; Wellington & Osborne, 2001; Yore et al., 2003), and writing have been clearly recommended (Klein, 1999; Rowell, 1997; Rivard, 1994).

#### Inquiry and the Science Writing Heuristic (SWH)

The writing support chosen for laboratories in the present study was the Science Writing Heuristic (SWH), developed by Hand and Keys (1999), which past research has

linked to improvements in conceptual understanding of science (Hand, Prain, & Wallace, 2002; Hand, Wallace, & Yang, 2004) and inquiry process skills, such as constructing and supporting claims and making meaningful connections between data, claims, and evidence (Hand, Prain & Wallace, 2002; Keys, Hand, Prain & Collins, 1999; Keys, 2000). As a writing strategy support, the SWH also shapes inquiry to be more reflective of scientific argumentation processes essential for science. Scaffolding is inherent in the format, through guided writing prompts that elicit students' beginning ideas about a topic and stimulate development of arguments by requiring identification of claims and supportive evidence. Additionally, students were encouraged by the teacher to expand on their beginning ideas and explore laboratory concepts to assist learning of technical terminology through associative meaning-making (Rivard, 1994). The SWH is aligned with constructivist approaches to teaching (Keys, Hand, Prain, & Collins, 1999; Prain & Hand, 1996) and sequences described in a conceptual change strategy for science lessons (Driver, 1988). The original focus of the SWH was intended to serve as dynamic support for inquiry investigations, although it has also been adopted as a guide for reading scientific articles during a research project investigating teachers' implementation of this tool (Gunel, Akkus, Hohenshell, & Hand, 2004). The SWH imparts flexibility for science teachers in choosing how to implement and modify the heuristic and the tool is adaptable to a variety of learning situations.

The SWH has two main components, one intended for the teacher and the other for students. The student component consists of the SWH, a template to guide students' thinking about the laboratory concepts. The teacher template assists the teacher in designing activities before, during, and after the laboratory, to enhance understanding of the concepts. One of the post-laboratory negotiation phases includes individual student reflection and writing. For

this writing piece, teachers in past studies using the SWH have generally chosen a culminating writing task, asking students to relate concepts explored in several completed SWH templates from different laboratories.

Recent studies incorporating the SWH during laboratory activities support the assertion that this template scaffolds students' inquiry and writing and leads to improvements in conceptual understanding (Hand, Prain, & Wallace, 2002; Wallace, Hand & Yang, 2002; Keys, Hand, Prain, & Sellers, 1999; Rudd, Greenbowe, & Hand, 2001; Tsoi, Keys, & Hand, 2001). For example, seventh-grade students using the SWH scored higher on both multiple choice and conceptual questions than students who wrote using a traditional format (Wallace, Hand, & Yang, 2002). Similar results have been found on conceptual measures at both the high school level with tenth-grade students (Hand, Prain, & Wallace, 2002) and the university level with freshman chemistry students (Rudd, Greenbowe, & Hand, 2001). Preliminary results from another study also indicate that low achieving students using the SWH outperform low achieving students in control groups (Grimberg, Omar, Gunel, & Hand, 2003). While collectively these results are exciting and promising, generalization would be premature due to the limited number of studies in certain contexts, each with different instructional topics or content goals. In addition, these studies were implemented by teachers who were familiar with the SWH, had graduate course work in constructivism and science literacy, and had a network of support from researchers throughout the process of incorporating the SWH into their curriculum for study. More research is needed in a wider variety of classroom contexts, comparing and contrasting topics, not only to determine if certain goals or concepts are more suited to this kind of support, but also to determine if age

and development enhance or diminish the potential benefit for students who have had more exposure and experience with particular content.

In assessing learning outcomes from the SWH studies, a larger question remained concerning student learning within the full writing experience. In the study by Wallace, Hand, and Yang (2002), the post-test was administered after the full sequence of the SWH, that is, after the culminating writing task. A larger question remained: what was the major factor contributing to student learning, was it directly resulting from the SWH guiding the writing for inquiry activities, or was the combination of two distinct writing types, laboratory writing along with a synthesis writing component required? The present study sought to address this question in particular. Three research questions derived from these various literatures that framed the present study were:

1. In maintaining the topic of cells, are previous results (Hand, Wallace, & Yang, 2004) reproducible in a different environment with older participants? Specifically, do high school students who use a heuristic focused on scaffolding argumentation, writing, and inquiry during laboratory activities perform better on conceptual and/or recall questions than students who use a more traditional laboratory report format?
2. After which components of the full SWH sequence will there be evidence of learning gains? Specifically, in answering conceptual and recall questions, will differences between groups be evident immediately after completing the laboratory writing activities (as in question 1), or is a consolidating writing task, in this case a summary report, necessary to maximize learning? And are any detectable benefits found in completing the summary task dependent upon the type of laboratory writing experience as described in question 1?

3. Are there performance differences on conceptual and/or recall questions related to sex and the type of laboratory writing experience?

### Research Design

The primary research team consisted of one male educational researcher and two female teachers pursuing graduate degrees in education. One teacher, a doctoral candidate with two years of teaching experience, was familiar with the SWH, which was used in developing units of study, conducting past research, and as part of her teaching approach to laboratory work. The second teacher was a master of education candidate with four years of teaching experience. Both teachers had completed graduate coursework in science literacy with a constructivist theoretical focus. Through collaboration, the research team identified main concepts for the cell unit, developed the testing instruments to examine the learning outcomes from completing the writing tasks, and modified the interview and survey questionnaires to serve the present study. Throughout the investigation, the team met regularly to discuss pedagogical strategies, classroom observations, and emerging concepts for developing categories (Strauss & Corbin, 1998).

The design centered on teaching the same year 10 cell biology unit for seven-weeks at two separate high schools to determine if findings would replicate. The population of the schools and composition of students within the courses at each high school were different; thus, two parallel studies were conducted, with both graduate students as regular classroom teachers, one at each site. The site in Study 1 included European-American students from predominantly middle-class backgrounds attending a mid-western, suburban, parochial high school with a minority representation of 7.5% with approximately 1200 total students. Study 2 included students attending a larger mid-western, urban, public high school with

approximately 2300 total student population, with 14.9% minority representation and 23.4% receiving reduced-lunch support.

## Method

To address the guiding research questions framed from the literature review, a mixed-method, quasi-experimental, pre-post test design with three groups was used. An interpretive approach was adopted for the qualitative portion of the study. Hypotheses were developed from the data (Strauss & Corbin, 1998), which consisted of open-ended surveys and interviews specifically targeting the research questions. The hypotheses are presented as a set of outcomes in the results section. Qualitative and quantitative methods were considered complementary; we anticipated the qualitative component would enhance interpretation of any quantitative findings.

The specific questions addressed in the quantitative component of these studies were: (1) On an assessment administered directly following laboratories, do students who use the SWH during laboratories perform better than students in a Control group who completed laboratories using a traditional format? (2) On an assessment following summary report writing, do students in the following conditions perform differently, (a) students who had the same laboratory writing experience (SWH), but wrote to different audiences (teacher compared to peers) and (b) students who had different laboratory writing experiences (SWH group compared to Control group), but wrote summary reports to the same audience (teacher)? and (3) Are there differences between males and females in performance on tests between groups?

The purpose of the qualitative component was to compare students' perceptions of using two different writing-to-learn strategies. The specific research questions were: (1)

What particular characteristics of the writing tasks do students identify as important for improving their understanding? and (2) In comparing students experiencing different laboratory writing tasks, what distinctions are present in how students attribute writing to learning?

Study 1 Participants. The participants in Study 1 included 91 high school students in grades nine and ten enrolled in one of four sections of an advanced biology course. These students were 'tracked' prior to the study and course admittance was dependent on middle school grades in science and mathematics courses, standardized test scores taken in middle-school, scores on an entrance exam as well as parental agreement and middle-school teacher recommendations.

Study 2 Participants. In Study 2, 128 ninth through twelfth grade students, predominantly in grade ten, in six sections of a regular biology course participated.

#### Cells Unit

Concepts framing the cell unit outlined next were aligned with standards and benchmarks of both high schools as well as the national standards (NRC, 1996, p.184). Unit topics chosen targeted the unifying concept of form and function as it applies to cellular structures and functions. The three content focus concepts were: (1) a living system composed of one or more cells has structures that conduct functions; (2) different structures are present in different types of cells (plants, animals and prokaryotes) serving different functions; and (3) different types of cell transport allow cells to move materials facilitating functions for survival. Additionally, students also practiced their "abilities necessary to do scientific inquiry" (1996, p. 173) during laboratory work. Students were reminded to think about concepts in the unit that might be important in testing their ideas during laboratories.



Their freedom and independence in designing experiments varied depending on the nature of the concept focused on in the task, which increased in complexity as the unit progressed from a focus on structures initially to a focus on processes towards the end of the unit.

During the unit, students worked in groups to complete six laboratory activities and each individual submitted a written report. They were then asked to complete a test on cells. After this test, students were required to write a summary report of the unit, before being retested. Essay questions on cell structure and transport were modified from past Advanced Placement Biology Exam questions (1993) and textbook resources were also used in developing both extended response and multiple-choice questions (EXAMgen, 1996-1998). Figure 1 displays examples of extended response questions used to target these concepts.

1. Membranes are important structural features of cells. Describe how membrane structure is related to the transport of materials across a membrane using both active and passive transport.
2. A laboratory assistant prepared solutions of 80%, 60%, 40%, and 20% sucrose but forgot to label them. After realizing the error, the assistant randomly labeled the flasks containing these four unknown solutions as flask A, flask B, flask C, and flask D. Design an experiment, based on the principles of diffusion and osmosis that the assistant could use to determine which of the flasks contains each of the four unknown solutions.
3. Describe the structure of a prokaryotic bacteria cell and explain how it differs in structure from the eukaryotic onion cell.
4. Compare and contrast a plant cell (onion cell) and an animal cell (human cheek cell). Include at least 3 comparisons in your answer.

Figure 1. Sample extended response questions from the two test forms, A and B.

### Pedagogical Sequence

The studies were situated in classroom contexts, thus the design and methods of data collection are situated within students' instructional experiences.

#### Groups Defined by Writing Tasks

In both studies, three groups were utilized, a Control group, a Science Writing Heuristic group, and a Peer Review group. All groups experienced the same background instruction and series of six laboratory experiences. Within each class, students worked in small-groups to complete laboratory activities and teachers encouraged discussion among and between all small-groups within a class. The major classroom study groups differed in their exposure to a combination of two different writing tasks, writing during laboratories and a summary report.

Students in the first group, the Control group, wrote formal laboratory reports in a conventional format, stating a hypothesis, recording materials and procedures, compiling results, and summarizing findings in discussion and conclusion sections. Students in the second group, the Science Writing Heuristic (SWH) group, used a modified format with their six laboratory reports; their writing was guided through the use of a Science Writing Heuristic (figure 2; full description in Hand and Keys, 1999). While discussion was encouraged for all groups, the SWH was conceptualized to promote dialogue, facilitate discussions, and scaffold argumentation for the purpose of inquiry. After the six laboratories, students in the Control and SWH groups individually completed a summary report using Microsoft® Word and were directed to write for the teacher, who served as the audience.

Science Writing Heuristic Lab: \_\_\_\_\_

<b>1. Beginning ideas...</b> What questions do I have? (Students were guided to write testable questions with matching predictions.)
<b>2. Tests...</b> What did I do? (Students were asked to completely describe how they performed tests to answer their questions with enough detail to allow repeatability.)
<b>3. Observations...</b> What did I see? (Students recorded what they found from tests and were asked to appropriately represent data.)
<b>4. Claims...</b> What inferences can I make? (Students interpreted observations and explained what they thought happened.)
<b>5. Evidence...</b> How do I know? (Students justified claims by providing evidence for each claim.)
<b>6. Reading...</b> How do my ideas compare with others? (Students compared their ideas with 2 additional sources, one of which required a citation.)
<b>7. Reflection...</b> How have my ideas changed? (Students were asked to relate back to their beginning ideas and explain how these had changed.)

Figure 2. The Science Writing Heuristic Student Template used by SWH and Peer Review group Students (portion taken from Hand & Keys, 1999).

In the third group, the Peer Review group, students also used the Science Writing Heuristic to complete their laboratory writing; however, a web-based program from the University of California, Calibrated Peer Review™ (CPR), was used to complete the summary report. Peer Review students were given access to Microsoft® Word to construct their reports, which could readily be copied and pasted into the CPR web page. The format for CPR prompted students to write to an audience of their peers; after each student's summary report was submitted electronically, three different students anonymously reviewed the report. In their peer reviews, students responded to 20 question prompts calling attention to inclusion and accurate explanation of various terms and concepts. Each student in the Peer

Review group electronically reviewed three different summary reports written by other students also in the Peer Review group.

Students in all three groups used the same guidance prompts when writing their summary report (Appendix C). The focus concepts of the task were the same for all groups; the exact terms and concepts present in the electronic prompts for the Peer Review group were also displayed on an overhead rubric for students in the Control and SWH groups. Control and SWH group students were asked to self-assess their summary reports according to rubric prompts; they were reminded to first consult their peers, then the teacher if they had questions. Reviews by the Control and SWH group students were not as structured compared to students in the Peer Review group, who were required to respond in complete sentences when submitting reviews through computers. Thus, to ensure time on task was equal, students in the Control and SWH groups also completed chapter review questions from their textbook, writing responses in full and complete sentences incorporating the question as well as the answer(s). All time available for writing the report, constructing and reviewing feedback, and revision was equal for all three groups. In summary, the three groups differed in the full sequence of writing experiences, including the type of writing task used during their laboratories and the audience addressed for their summary report. Group compositions and instructional sequence are outlined in table 1.

Groups were assigned so that the first sections of the day were Control group students, the next were SWH group students, and the last class periods of the day were Peer Review students. Groups were assigned in this way due to scheduling issues concerning the availability of resources, as access to a sufficient number of computers with internet connections for each student in an entire class was only ensured at the end of the class day at

the site in Study 2. The clustering of group assignments was also considered to help maintain teachers' implementation consistency throughout the study so that each teacher's day would begin with traditional routines for Control group students and progress to SWH students and Peer Review students who required the same materials (SWH templates) and classroom procedures.

Table 1. Study 1 and Study 2 student composition and writing experiences in three groups: Control Group; Science Writing Heuristic (SWH) group; and Peer Review group.

Class Period	n	Group	Laboratory Writing	Summary Report Audience
Study 1				
1	24	Control	Traditional report	Teacher
2	24	SWH	SWH	Teacher
3	23	Peer Review	SWH	Peers
7	20	Peer Review	SWH	Peers
Study 2				
2	21	Control	Traditional report	Teacher
3	16	Control	Traditional report	Teacher
4	15	SWH	SWH	Teacher
5	21	SWH	SWH	Teacher
6	19	Peer Review	SWH	Peers
7	21	Peer Review	SWH	Peers

## Data Collection

The full sequence of instructional experiences and data collection were the same in both Study 1 and Study 2. Also, the assessments were considered aligned with instruction; thus, students' experiences across both studies are presented together in table 2, emphasizing two main differences between the studies were (1) the order in which testing instrument forms were administered and (2) the interviews consisted of only students in Study 1. A chemistry unit preceded both studies and scores were obtained for statistical analyses. The procedure of data collection included a series of measurements during three testing situations, a pre-test administered prior to the cell unit, and two post-tests, Test 1 and Test 2.

Following administration of the pre-test, background instruction on cell biology was provided and students engaged in six laboratory experiences. The first post-test, Test 1, was then given and used as a measure of learning resulting from these initial experiences. Next, students were guided with a planning template, and wrote a summary report for the purpose of integrating concepts of the six laboratories. Finally, students completed a second post-test, Test 2, to measure learning that occurred as a result of assimilation. Open-ended surveys were administered to students in Study 1 and Study 2 and interviews were conducted with a sample of students in Study 1 at the end of the investigation.

## Test Instruments

Indicators of learning were determined from scores on two different post-tests, targeting the same concepts. The tests were composed of 10 multiple choice, lower-order recall questions, and four extended response questions focusing on higher-order cognitive processes. Two forms of the test, A and B, were used (Appendix D and Appendix E); the questions were worded and ordered differently between forms. In Study 1, form A was used

for the pre-test and first post-test and form B was used for the second post-test. The reverse order of forms was used in Study 2. The two different, but equivalent forms of the test were used in each study as a means to assess students' ability to transfer learning and to overcome the limitation from repetition, as students would have been exposed to identical test questions a short period before had the same form been used throughout the study. Additionally, the alternate order of forms at the separate sites protected the study from the potential, although unlikely, possibility of student communication of test contents between sites since the schools were located 15 miles apart.

Initially, each teacher of the research team individually scored random samples of the extended response questions from students in her class. Teachers then met, reviewed the previously composed scoring rubric, discussed markings, and exchanged samples. Discussions were held until agreement was consistently reached and an inter-rater reliability of 90% on scored extended response questions between teachers was obtained, after which independent marking of the papers was conducted. Item analysis conducted on scores from both post-test conceptual questions using Cronbach's standardized alpha resulted in internal consistencies of .50 (form A) and .63 (form B) in Study 1 and the internal consistencies in Study 2 were .72 (form B) and .80 (form A).

The dependent variables measured included the total scores of the extended response questions, termed conceptual questions, and the total scores of the recall questions on each test, both calculated in percent correct and used in the statistical analyses. These questions were analysed separately to distinguish the type, or quality, of learning that might result.

Table 2. Sequence of Data Collection, Instructional Experiences, and Testing Instrument Forms in Study 1 and Study 2.

Week	Data Collection	Instructional Experience
0	Chemistry Unit Test	
1	Pre-Test Cells	
	Study 1 Form A	
	Study 2 Form B	
1-4		Background Instruction of Cellular Structures
		Lab 1: Human Cheek Cells
		Lab 2: Onion Bulb Cells
		Lab 3: Diffusion of $\text{KMnO}_4$
		Lab 4: Osmosis and Iodine Diffusion
		Lab 5: Potato Cores in NaCl Solution
		Lab 6: Decalcified Egg Models of the Cell Membrane
4	Post Test 1 Cells	
	Study 1 Form A	
	Study 2 Form B	
5		Summary Report: Draft Planning & Construction
6		Summary Report: Self & Peer Reviewing & Revision
7	Post Test 2 Cells	
	Study 1 Form B	
	Study 2 Form A	
7	Open-ended Survey	
7	Interviews	
	Study 1 only	

#### Open-ended Survey and Interview Questions

A previously developed survey instrument (Günel et al., 2003) was deemed appropriate and was only slightly modified as an open-ended questionnaire, composed of items targeting the research questions specific to the groups in the present study (figure 3). At the end of the unit, qualitative data was collected using this instrument and similar questions were used during semi-structured interviews. Collection of these data centered on establishing differences between students' perceptions of their writing tasks and identifying characteristics of writing that students attributed to their learning. All three groups of students in both studies anonymously completed the questionnaire. As such, data concerning



sex differences related to the research questions could not be obtained from these questionnaires and data from students with extended absences were not collected. In Study 1, a total of 88 surveys were completed (Control group  $n = 23$ ; SWH group  $n = 65$ ). In Study 2, 108 students completed the same instrument, although some questions were left blank resulting in the following maximum number of responses in each group (Control group  $n = 36$ ; SWH group  $n = 72$ ).

Illustrating differences in questions administered to Control group (CG) students, completing laboratory reports in traditional format, and students using the SWH template (SWH); extensions during interviews are indicated within parentheses.

- CG:** 1. You have had 2 different forms of writing during the cell unit, writing up each lab (hypothesis, procedure, results/discussion) and the Summary Laboratory Report. Which did you like best? WHY?
- SWH:** 1. You have had 2 different forms of writing during the cell unit, the Science Writing Heuristic (during labs) and the Summary Laboratory Report. Which did you like best? WHY?
- All:** 2. Were they the same for you or did you have to think differently when completing them? HOW?
- CG:** 3. Did writing the results and discussion help you learn? How?
- SWH:** 3. Did answering your own questions on the SWH help you learn better? WHY?
4. Did this (answering own questions) change how you were thinking about the activity (compared to what normally happens in science...during labs)? IF SO HOW?
- All:** 4/5. How much control of the activities did you feel that you had? Please explain.
- 5/6. How did you feel when answering the essay questions this last time, were you confident?
- 6/7. Were you learning AS you were writing? Please explain. (How do you think that works?)

Figure 3. Interview (Study 1 only) and Survey Questions for Groups in Study 1 and Study 2.

Data from initial responses to each question, indicating positive or negative reactions, were accumulated on a spreadsheet. Supporting explanations were also compiled on a separate spreadsheet under positive or negative responses. Three researchers independently performed a microanalysis (Strauss & Corbin, 1998) on questionnaire responses to identify patterns, translate these into categories, and determine the properties of each category through the process of open coding. These researchers then met to discuss differences in categories and grouping criteria related to the research questions; comparative analysis was used to group similar responses sharing properties under one category. Through discussions, categories were added or discarded, and groupings were modified so that criteria reasonably similar were grouped together under one category. After three meetings, consensus was reached and subsequently a coding scheme was established to the full satisfaction of each researcher. A scoring mechanism was used to categorize explanation phrases from the questionnaire responses, which represented subcategories presented in the results section. While it is recognized that qualitative analysis provides more depth of understanding, questionnaire data were quantified (%) to expedite comparison.

Due to resource availability, student accessibility, and time constraints, interviews only included a sample population of students ( $n = 24$ ) from Study 1. Semi-structured interviews (figure 3) were conducted with students using a partially random selection from each class in all three groups (Control group  $n = 5$ ; SWH group  $n = 7$ ; PR group  $n = 12$ ). Stratified random samples were used to obtain an interview sample balanced by sex and achievement level (High, Medium, and Low) based on course grades prior to the study. Grade range percentages used for achievement classification were: 76 to 84.4% = Low; 84.5 to 91.5% = Medium; and 91.6 to 97% = High. An independent researcher interviewed these

students at school and tape-recorded all sessions, which were later transcribed in full. While interviews were initially analysed independently of the surveys, due to similar questions in both of the instruments, the categories and explanation groupings (subcategories) previously developed in survey analysis were considered appropriate and retained for analysis of the interviews. Interview responses were richer in detail and as such, were used to expand on results found in analysis of questionnaires and quantitative findings. Interviews were reanalysed in-depth to identify evidence that confirmed the developing themes as well as the evidence that refuted these themes.

Four activities contributed to credibility and trustworthiness (Lincoln & Guba, 1985). Three data sources were used for the technique of triangulation, tests, surveys, and interviews. Prolonged engagement and persistent observation were attained in that both graduate students were also full-time classroom teachers at their sites for more than one year prior to the investigation. Both teachers' attention to contributing factors was evident in discussions during regular research meetings with the principal investigator. Peer debriefing was achieved through the relation of the teacher in Study 1 and the other two researchers who performed microanalyses on the surveys.

### Statistical Analyses

All statistical procedures were performed using the Statistical Program for the Social Sciences (SPSS). Cronbach's standardized item alpha test of reliability was used to determine the internal consistency of conceptual questions on both post-tests.

The two pre-study measures used to ensure the treatment assignments did not result in threats to internal validity through differential group selection were the scores on the previous chemistry unit test and the pre-test. Correlations were run to identify factors for

inclusion in the model; sex was used as a grouping (independent) variable, and both chemistry unit and pre-test scores served as covariates. Dependent variables were conceptual and recall question scores on Test 1 and Test 2, which were analysed using ANCOVA, with scores from the chemistry test and pre-test as covariates for Test 1 analyses and scores on Test 1 were added as a covariate in analyses of Test 2.

Frequencies obtained from questionnaire responses were analysed with the non-parametric, chi-square two-sample test. Comparisons were made within each group to determine if the number of positive and negative responses differed significantly among members of the same group. For example, regarding questions concerning the laboratory writing, analyses of students in the Control group were determined and then were compared to students who completed laboratory writing using the SWH (SWH and Peer Review groups).

In addressing the first research question, Control group students' scores on Test 1, administered immediately following laboratory activities, were compared to students in the SWH group to determine if differences existed due to the format used in laboratory writing. To inform the second research question, two sets of comparisons were conducted as opposed to one comparison of all three groups. This method was chosen due to potential confounding experiences from laboratory writing and summary report audience, which would have been the case in any contrast involving the Control group and the Peer review group. Thus, after completing the summary report, to determine if there were differences in performance on Test 2 items resulting from differences in laboratory format writing, Control group students' scores were compared to scores of SWH students as both of these groups wrote to similar audiences for their summary reports. To determine if differences were directly related to

summary report writing, students in the SWH group were compared to those in the Peer Review group as students in these two groups conducted laboratories in similar formats, but wrote to different audiences for their reports. In all quantitative comparisons, sex was included in the models to detect differences in performance on test items due to sex, which informed the third research question.

## Results

Study 1 and Study 2 results are presented separately with results from qualitative interviews (Study 1) following the quantitative findings.

### Study 1

Results from comparisons using the General Linear Model Univariate procedure indicated no significant differences ( $p > .05$ ) between groups on measures collected prior to the writing experiences in Study 1 (table 3). No differences were found between the Control group, the Science Writing Heuristic (SWH) group, or the Peer Review group for the previous chemistry unit test scores (Chemistry), the combined score of conceptual questions on the pre-test (PreConceptual), or the total score of the recall questions on the pre-test (PreRecall). While a trend toward a significant difference was found between groups for the PreConceptual question measure  $F(2,85) = 2.80$ ,  $p = .066$ , partial  $\eta^2 = .062$ ,  $MSE = 62.90$ , Post Hoc Bonferroni tests indicated these groups did not differ significantly ( $p > .05$ ).

### Comparisons of different laboratory writing experiences

Considering males and females together, Study 1 results from ANCOVA analysis of Test 1 dependent variables (table 4) indicated no significant difference between students who wrote traditional laboratory reports (Control group) and students who completed laboratory

reports using the Science Writing Heuristic (SWH group). However, a significant interaction was found between the laboratory writing group and sex for one dependent variable. In

Table 3. Descriptive Statistics of Data Prior to Writing for the Control group, the Science Writing Heuristic (SWH) group, and the Peer Review group in Study 1.

Group	Sex	Chemistry			PreConceptual		PreRecall	
		n	M	SD	M	SD	M	SD
All students	Males	52	82.47	10.81	10.58	8.62	46.92	19.46
	Females	39	82.75	10.36	10.00	7.12	45.90	15.68
Control		24	81.25	10.42	8.92	7.22	45.83	19.54
	Males	13	80.11	10.54	9.08	7.01	40.77	22.16
	Females	11	82.60	10.61	8.73	7.81	51.82	14.71
SWH		24	81.13	9.89	13.42*	7.56	46.25	14.69
	Males	10	81.86	7.65	15.20	9.85	49.00	18.53
	Females	14	80.61	11.48	12.14	5.46	44.29	11.58
Peer Review		43	84.15	11.02	9.40	8.30	46.98	18.84
	Males	29	83.74	11.92	9.66	8.57	48.97	18.58
	Females	14	85.00	9.22	8.86	7.99	42.86	19.39

*Note.* \*indicates the highest mean for comparison in which a trend was found ( $p = .066$ ).

figure 4, it appears that SWH females have an advantage over Control females and SWH males in answering conceptual questions.

To pinpoint differences related to the interaction found in analysis of Test 1 conceptual question total score, three subsequent ANCOVAs, using the same covariates,

were performed; these comparisons were chosen based on the study question to determine differences related to the factor of sex. Adjusted means and non-overlapping standard error bars (displayed in figure 4) were inspected to inform comparisons. The significance level used for these subsequent comparisons was .016 (p value .05/3). The first compared sex within the SWH group, indicating that females scored higher than males on the conceptual question total score on Test 1. The second compared females in both groups, indicating that females in the SWH group also scored higher than females in the Control group. The third compared sexes within the Control group; however, males and females did not differ significantly in the Control group ( $p = .323$ ).

Test 1 Total Conceptual Questions. Significant effects were found for the chemistry unit score covariate  $F(1,85) = 21.07$ ,  $p = .000$ , partial  $\eta^2 = .199$ , the pre-test total conceptual question score covariate  $F(1,85) = 7.07$ ,  $p = .009$ , partial  $\eta^2 = .077$ , and the interaction between laboratory writing group and sex,  $F(1,85) = 5.95$ ,  $p = .017$ , partial  $\eta^2 = .065$ , MSE = 123.15 (illustrated in figure 4). No significant differences were found for the main effect of laboratory writing group or sex.

In further analysis of the interaction using the subsequent ANCOVA comparing sex within the SWH group, females ( $n=28$ ;  $\text{adjM}=58.33$ ;  $\text{SE}=2.14$ ) scored significantly higher than males ( $n=39$ ;  $\text{adjM}=50.12$ ;  $\text{SE}=1.81$ ;  $F(1,63) = 8.56$ ,  $p = .005$ , MSE = 128.11). The second comparison indicated that females in the SWH group ( $n=28$ ;  $\text{adjM}=57.77$ ;  $\text{SE}=1.90$ ) also scored higher than females in the Control group ( $n=11$ ;  $\text{adjM}=48.22$ ;  $\text{SE}=3.05$ ;  $F(1,35) = 7.03$ ,  $p = .012$ , MSE = 101.11).

Test 1 Total Recall Questions. A significant effect was found for the chemistry unit score covariate  $F(1,85) = 12.72$ ,  $p = .001$ , partial  $\eta^2 = .130$ , MSE = 126.83. No significant

differences were found for the pre-test total recall score covariate, the main effect of laboratory writing group, sex, or the interaction between laboratory writing group and sex.

Table 4. Adjusted means, standard errors, and sample sizes of laboratory writing groups (Control group and SWH group) Test 1 scores in Study 1.

Test 1	Control		SWH		Sex x Group				
	Males		Females		Males		Females		Interactions
	adj M	SE	adj M	SE	adj M	SE	adj M	SE	
Conceptual	52.84	3.10	48.08	3.35	49.67	1.78	57.89	2.10	.017
Total Recall	86.34	3.16	85.69	3.42	85.83	1.81	81.71	2.14	.530
N	13		11		39		28		

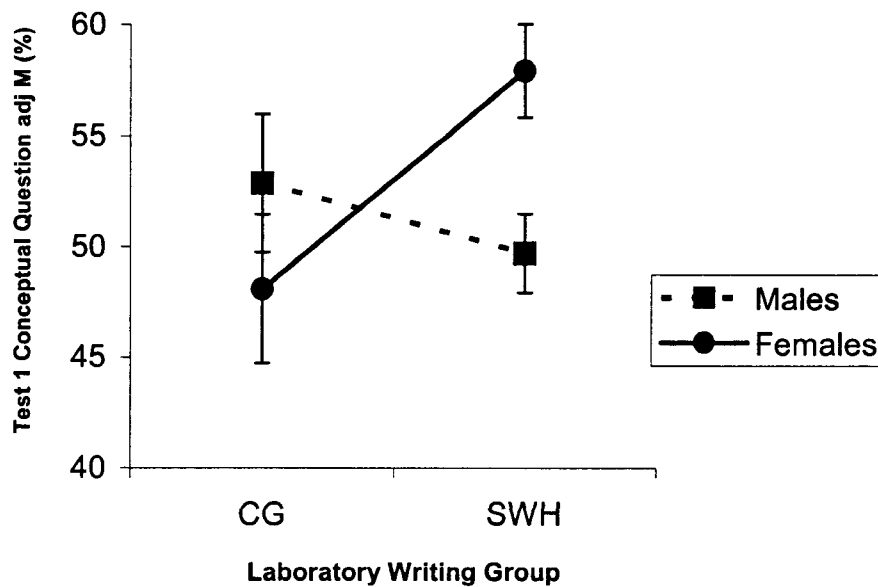


Figure 4. Interaction between laboratory writing group and sex: Illustration of differences in performance on Test 1 conceptual questions between males and females writing in traditional formats (Control group, CG) and those using the SWH in Study 1.



### Comparisons Following Summary Report Writing

After students wrote summary reports, the groups differed in either laboratory writing experiences, the audience of their summary report, or a combination of both. Due to these differences between the three groups, two separate comparisons of groups were conducted to maintain one of these variables constant in addressing questions related to student performance on Test 2. ANCOVA was used for all comparisons with three covariates included in the model, the previous chemistry unit score, Pre-test score, and Test 1 score.

To determine if the audience of summary writing influenced performance on Test 2, students in the SWH group who wrote to the teacher (SWH group) were compared to students who wrote to an audience of their peers (Peer Review group). In this comparison, the type of laboratory writing experience was held constant as both groups wrote laboratory reports using the SWH.

The second comparison maintained audience of summary report writing as a constant, comparing students who wrote to the teacher, SWH group and Control group, to determine if performance on Test 2 was affected by earlier laboratory writing experiences.

### Same Laboratory Writing, Different Summary Report Audience

In Study 1, no differences in performance on Test 2 were found between SWH group students who wrote summary reports for the teacher, and students in the Peer Review group, who wrote to an audience of their peers (Table 5). While results indicated a trend toward significance ( $p < .10$ ) for interactions between audience groups and sex, none were found significant ( $p > .05$ ).

Test 2 Total Conceptual Questions. Test 1 conceptual question total score covariate was significant in the model  $F(1,60) = 22.762, p = .000, \text{partial } \eta^2 = .275, \text{MSE} = 106.81$ . No

significance was found for the pre-test total conceptual question score covariate, the chemistry unit score covariate, the main effect of group, sex, or the interaction between group and sex.

Test 2 Total Recall Questions. No significant differences were found in the model for the chemistry unit score covariate, the pre-test total recall score covariate, Test 1 total recall score covariate, the main effect of group, sex, or the interaction between group and sex.

Table 5. Adjusted means, standard errors, and sample sizes of SWH Group and Peer Review Group Test 2 Scores in Study 1.

Test 2	SWH				Peer Review				Sex x Group
	Males		Females		Males		Females		Interactions
	adj M	SE	adj M	SE	adj M	SE	adj M	SE	<i>p</i>
Conceptual	87.97	3.35	83.81	2.87	80.75	2.01	87.13	2.82	.059
Total Recall	85.93	3.30	83.39	2.89	89.45	1.94	88.53	2.80	.772
n	10		14		29		14		

#### Same Summary Report Audience; Different Laboratory Writing

In Study 1, dependent variables on Test 2 were analysed to determine performance differences between students who wrote summary reports to the same audience of the teacher, but had different prior writing experiences during laboratories. Significant differences were found between groups in performance on Test 2 conceptual questions, indicating that students in the SWH group, who wrote during laboratories with guidance on the SWH, outperformed students in the Control group, who wrote laboratories using a

traditional format (table 6). No differences were found between males and females nor were there significant interactions between laboratory writing group and sex.

Test 2 Total Conceptual Questions. Significant effects were found for the chemistry unit score covariate  $F(1,41) = 4.24$ ,  $p = .046$ , partial  $\eta^2 = .094$ , and the main effect of group defined by differences in laboratory writing  $F(1,41) = 6.68$ ,  $p = .013$ , partial  $\eta^2 = .140$ ,  $MSE = 90.27$ . No significance was found in the model for the pre-test total conceptual question score covariate, Test 1 total conceptual question covariate, sex, or the interaction between group and sex. Students in the SWH group scored higher than students in the Control group.

Test 2 Total Recall Questions. No significant differences were found in the model for the chemistry unit score covariate, the pre-test total recall score covariate, test 1 total recall score covariate, the main effect of group, sex, or the interaction between group and sex.

Table 6. Adjusted means, standard errors, sample sizes, and estimates of effect size of Control group and SWH group Test 2 Scores in Study 1.

Test 2	Control		SWH		$p$	Cohen's $d$
						pooled SD
	adj M	SE	adj M	SE		
Conceptual	79.20	2.05	87.07	2.06	.013	.62
Total Recall	88.37	2.28	84.28	2.28	.214	
n	24		24			

Based on findings from the previous two comparisons, we assumed that if the audience of the summary report had no influence on Test 2 performances, then the assertion that SWH writing during laboratories had a positive impact on Test 2 performance might be

strengthened by comparing all students who wrote laboratory reports using the SWH ( $n=67$ ) to students who wrote using the traditional format (Control group,  $n=24$ ). However, due to the potentially confounding variable of audience, the question further explored was adjusted to, "is performance on an assessment after the full sequence of writing experiences influenced by the type of laboratory writing, regardless of the summary report audience (i. e. not controlling for this variable)?"

The assertion was not further strengthened as no differences ( $p > .05$ ) were found between groups for either Test 2 dependent variables. SWH group students scored similarly on conceptual question total score ( $\text{adjM}=83.40$ ;  $\text{SE}=1.33$ ) to Control group students ( $\text{adjM}=80.41$ ;  $\text{SE}=2.21$ ) with only the covariate of Test 1 conceptual question significant in the model,  $F(1,84) = 19.94$ ,  $p = .000$ , partial  $\eta^2 = .192$ ,  $\text{MSE} = 113.55$ . Test 2 total recall scores were also similar between SWH ( $\text{adjM}=87.28$ ;  $\text{SE}=1.25$ ) and Control group students ( $\text{adjM}=88.89$ ;  $\text{SE}=2.08$ ) with the covariate of Test 1 total recall score significant in the model  $F(1,84) = 4.68$ ,  $p = .033$ , partial  $\eta^2 = .053$ ,  $\text{MSE} = 101.76$ . However, interpretation of these findings is complicated by the inclusion of a potentially confounding variable of audience in this particular comparison (see trend toward significant interaction table 5).

Highlighting the main quantitative outcomes in Study 1, after different laboratory writing experiences, no difference was found on Test 1 performance between students who wrote laboratories using the SWH and students who completed laboratory reports in the traditional format. Although an interaction indicated that females in the SWH group outperformed males in the SWH group and females in the Control group on Test 1 conceptual questions. After completing the summary report, when comparing groups of students who wrote to the same audience of the teacher, SWH students did perform better on

Test 2 conceptual questions compared to students in the Control group who had written laboratory reports using a traditional format. Students who had similar laboratory experiences with the SWH did not differ in performance on Test 2 (SWH group compared to Peer Review group).

## Study 2

Using the General Linear Model Univariate procedure, no differences were found between sexes or between groups for the previous chemistry unit test scores (Chemistry), or the combined score of conceptual questions on the pre-test (PreConceptual). A trend toward a significant difference was found between groups for the PreConceptual question measure  $F(2,116) = 2.50$ ,  $p = .086$ , partial  $\eta^2 = .041$ ,  $MSE = 41.83$ ; however, Post Hoc Bonferroni tests indicated these groups did not differ significantly ( $p > .05$ ).

Results did indicate significant differences between groups  $F(2,116) = 4.07$ ,  $p = .020$ , partial  $\eta^2 = .066$ , and between males and females  $F(1,116) = 5.64$ ,  $p = .019$ , partial  $\eta^2 = .046$ ,  $MSE = 265.78$  existed for the pretest total score on recall questions (PreRecall) in Study 2 (table 7). Males scored higher than females; Post Hoc Bonferroni comparisons indicated that Control group students scored higher than Peer Review group students ( $p = .041$ ).

## Comparisons of different laboratory writing experiences

In Study 2, results from analysis of Test 1 dependent variables (table 8) indicated no differences between the main effect of the type of laboratory writing experiences (Control group compared to the SWH group) for either dependent variable measured. Differences were found for sex across the groups, as females outperformed males on conceptual questions. However, no significant interactions were found between the type of laboratory writing group and sex for either dependent variable.

Table 7. Descriptive Statistics of Data Prior to Writing for the Control Group, the Science Writing Heuristic (SWH) Group, and the Peer Review Group in Study 2.

Group	Sex	Chemistry			PreConceptual		PreRecall		
		M	SD	n	M	SD	M	SD	n
All students	Males	76.02	11.67	53	4.98	6.77	38.04 <sup>a</sup>	16.37	51
	Females	74.62	14.47	71	4.84	6.32	31.41 <sup>b</sup>	17.18	71
Control		78.60	12.78	38	4.33	6.75	38.72 <sup>c</sup>	17.65	39
	Males	78.73	11.52	14	4.91	7.65	47.86	18.88	14
	Females	78.52	13.70	24	4.00	6.33	33.60	14.97	25
SWH		74.89	13.13	40	6.80	7.16	34.74	18.56	38
	Males	76.17	13.29	18	7.23	7.66	33.53	16.93	17
	Females	73.84	13.21	22	6.45	6.91	35.71	20.14	21
Peer Review		72.70	13.58	46	3.80	5.34	29.78 <sup>d</sup>	14.38	45
	Males	74.07	10.41	21	3.13	4.80	35.00	11.00	20
	Females	71.55	15.90	25	4.33	5.77	25.60	15.57	25

*Note.* Different sample sizes result from incomplete data sets due to student absences.  
<sup>a-b; c-d</sup> indicates means with different superscripts differ.

Test 1 Total Conceptual Questions. Significant effects were found for the chemistry unit score covariate  $F(1,112) = 38.22, p = .000$ , partial  $\eta^2 = .254$ , the pre-test total conceptual question score covariate  $F(1,112) = 28.09, p = .000$ , partial  $\eta^2 = .201$ , and sex  $F(1,112) = 9.71, p = .002$ , partial  $\eta^2 = .080$ ,  $MSE = 146.35$ . The main effect of laboratory writing group was not significant, nor was the interaction between laboratory writing group and sex.

Females ( $n=68$ ;  $\text{adjM}=38.57$ ;  $\text{SE}=1.54$ ) performed better than males ( $n=50$ ;  $\text{adjM}=30.84$ ;  $\text{SE}=1.95$ ).

Test 1 Total Recall Questions. A significant effect was found for the chemistry unit score covariate  $F(1,112) = 27.68$ ,  $p = .000$ , partial  $\eta^2 = .029$ ,  $\text{MSE} = 334.81$ . No differences were found in the pre-test total recall score covariate, the main effect of laboratory writing group, sex, or the interaction between laboratory writing group and sex.

Table 8. Adjusted means, standard errors, and sample sizes of Control Group and SWH group Test 1 Scores in Study 2.

Test 1	Control				SWH			
	Males		Females		Males		Females	
	adj M	SE	adj M	SE	adj M	SE	adj M	SE
Conceptual	32.28	3.36	40.28	2.50	29.39	1.99	36.86	1.84
Total Recall	52.45	5.30	52.97	3.76	53.63	3.01	56.20	2.79
n	13		24		37		44	

*Note.* Sample size was reduced ( $n = 118$ ) due to student absences.

#### Comparisons Following Summary Report Writing

To address the questions related to performance on Test 2 items, the same two ANCOVA comparisons were conducted in Study 2 as in Study 1 due to differences between groups in laboratory writing experience, the audience of the summary report, or a combination of both (these comparisons were previously described in Study 1).

#### Same Laboratory Writing; Different Summary Report Audience

In Study 2, to determine influence from writing summary reports to separate audiences (teacher as audience compared to peers as audience), no differences were found on

Test 2 performance (table 9) between SWH group and Peer Review group students, who had the same laboratory writing experience using the SWH. An interaction between audience group and sex indicated females writing to the teacher were advantaged in performance on Test 2 conceptual questions.

Test 2 Total Conceptual Questions. Significant effects were found for the chemistry unit score covariate  $F(1,69) = 4.84, p = .031$ , partial  $\eta^2 = .066$ , Test 1 conceptual question total score covariate  $F(1,69) = 23.72, p = .000$ , partial  $\eta^2 = .256$ , and the interaction between audience group and sex,  $F(1,69) = 4.75, p = .033$ , partial  $\eta^2 = .064$ ,  $MSE = 190.07$  (displayed in figure 5). No significance was found for the pre-test total conceptual question score covariate, sex, or the main effect of group defined by summary report writing audience.

Inspection of the interaction illustrated in figure 5 indicated one further analysis was appropriate, for which the same ANCOVA model was used, comparing females to males in the SWH group (teacher as audience). Females in the SWH group ( $n=20$ ;  $adjM=52.07$ ;  $SE=3.08$ ) scored higher than SWH males ( $n=16$ ;  $adjM=41.29$ ;  $SE=3.49$ ) with chemistry unit covariate  $F(1,31) = 6.65, p = .015$ , partial  $\eta^2 = .177$ , Test 1 conceptual question score covariate  $F(1,31) = 22.77, p = .000$ , partial  $\eta^2 = .423$ ,  $MSE = 171.98$ , and the main effect of sex  $F(1,31) = 4.86, p = .035$ , partial  $\eta^2 = .136$ , significant in the model. Pre-conceptual question total score covariate was not significant in the model.

Test 2 Total Recall Questions. Significant effects were found for the chemistry unit score covariate  $F(1,69) = 9.20, p = .003$ , partial  $\eta^2 = .118$ , the Test 1 total recall score covariate  $F(1,69) = 6.50, p = .013$ , partial  $\eta^2 = .086$ ,  $MSE = 263.91$ . No significance was found for the pre-test total score covariate, the main effect of group defined by summary report audience, sex, or the interaction between group and sex.



Table 9. Adjusted means, standard errors, and sample sizes of SWH group and Peer Review group Test 2 Scores in Study 2.

Test 2	SWH		Peer Review				Sex x Group		
	Males		Females		Males		Females		Interactions <i>p</i>
	adj M	SE	adj M	SE	adj M	SE	adj M	SE	
Conceptual	35.91	3.56	49.37	3.22	46.36	3.33	45.71	2.97	.033
Total Recall	65.08	4.09	69.58	3.66	60.47	3.85	64.03	3.56	.903
n	16		20		18		22		

*Note.* Missing data from Test 1 used as a covariate in the model was due to extended absences of 2 Peer Review group females (n=22), causing an incomplete data set (n = 76).

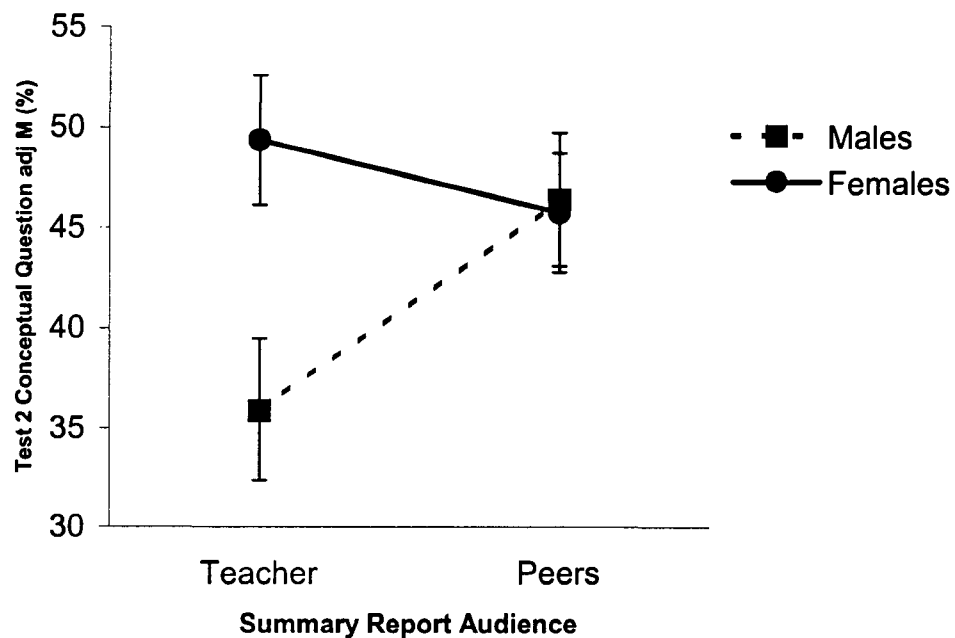


Figure 5. Interaction between groups defined by the audience of summary report writing and the performance of males and females on Test 2 conceptual questions in Study 2.

### Same Summary Report Audience; Different Laboratory Writing

In Study 2, no differences in performance on Test 2 dependent variables were found between students in the Control group and students in the SWH group. Students in both groups wrote summary reports to the same audience (the teacher), but had different prior writing experiences during laboratories. A trend toward an interaction between laboratory writing group and sex was found for performance on conceptual questions; thus adjusted means are reported for both sexes in each laboratory writing group (table 10).

Test 2 Total Conceptual Questions. Significant effects were found for the chemistry unit score covariate  $F(1,65) = 9.13$ ,  $p = .004$ , partial  $\eta^2 = .123$ , and the Test 1 total conceptual question score covariate  $F(1,65) = 32.27$ ,  $p = .000$ , partial  $\eta^2 = .332$ ,  $MSE = 176.91$ . No significance was found in the model for the pre-test conceptual question score covariate, the main effect of group defined by differences in laboratory writing, sex, or the interaction between group and sex.

Test 2 Total Recall Questions. Significant effects were found for the chemistry unit score covariate  $F(1,65) = 4.89$ ,  $p = .031$ , partial  $\eta^2 = .070$ , the Test 1 total recall score covariate  $F(1,65) = 6.48$ ,  $p = .013$ , partial  $\eta^2 = .091$ ,  $MSE = 313.74$ . No significance was found for the pre-test total score covariate, the main effect of group defined by summary report audience, sex, or the interaction between group and sex.

In Study 2, no differences were found in quantitative comparisons between treatment groups on either Test 1 or Test 2 dependent variables. On Test 1, females in both laboratory writing groups outperformed males on conceptual questions. On Test 2 conceptual question total score, an interaction was found between groups defined by summary report audience and sex, indicating females who wrote summary reports to the teacher and had written

Table 10. Adjusted means, standard errors, and sample sizes of Control Group and SWH group Test 2 Scores in Study 2.

Test 2	Control		SWH		Sex x Group				
	Males		Females		Males		Females		Interaction <i>p</i>
	adj M	SE	adj M	SE	adj M	SE	adj M	SE	
Conceptual	49.20	3.73	49.02	2.88	41.05	3.51	53.42	3.03	.056
Total Recall	69.67	5.14	67.77	3.74	67.30	4.45	71.94	4.00	.464
n	13		23		16		20		

*Note.* Missing data due to student absences resulted in an incomplete data set ( $n = 72$ ).

laboratories with the SWH had some benefit compared to males with those same experiences.

#### Open-ended Survey Comparisons and Interviews

Dimensions of major categories developed from survey responses were dichotomous in that either a positive or negative response to the question was indicated or one writing type was preferred (see Appendix B for detailed coding tables compiling results in Study 1 and Study 2). Subcategories were developed from students' explanations of their responses; single quotations demarcate survey responses from italicized interview responses of students in Study 1. Both categories and subcategories are presented in tables 11 through 22, which represent responses to survey questions by students in both Study 1 and Study 2.

#### *Study 1*

Although not statistically significant, more surveyed students in the Control group (70%) tended to prefer laboratory writing compared to the summary report ( $\chi^2 = 3.52$ ,  $df = 1$ ,  $p < .061$ ), while a more equal distribution (53% preferred SWH writing) was found among

students completing laboratories using the SWH ( $\chi^2 = .258$ ,  $df = 1$ ,  $p < .611$ ; table 11). Most Control group students (77.8%) surveyed indicated preference was based on the format for laboratory writing. Students interviewed from the Control group viewed the laboratory format as being more structured. As Rhea (CG-H) explained, *'We were given more directions and it was easier to follow and put exactly what she [the teacher] wanted and not have to come up with anything'*. Miles (CG-M) preferred writing during the labs to the summary report because, *'it was shorter...you just kind of had to copy down what you were doing, you didn't need to think about how to organize it'*. For Miles, the laboratory writing required less mental effort than the summary report.

Many students (60.0%) in the SWH group also specified their preference was related to the format for their laboratory writing, which was the SWH template. Jay (SWH-M) found the guiding questions useful as they *'gave you an idea of what to look for'*. Several responses (28.6%) also indicated that the SWH helped students develop knowledge by allowing them to *'think about the experiments'* and *'focus understanding on the labs'*. Only one Control group student (5.5%) noted the laboratory writing helped to *'think outside the box'*. Students in both groups who preferred the summary report revealed knowledge development, as in completing this task they *'explained everything'*, it allowed them to *'relate'* information, *'make connections'*, or they found elements of the format useful, such as *'summarizing'* according to a *'rubric'*.

Significant differences found in chi-square analysis of questionnaires resulted in the following outcomes:

Outcome 1. More students (81%) in the SWH group recognized that they had to think differently when completing the two writing types ( $\chi^2 = 25.0$ ,  $df = 1$ ,  $p < .001$ ) compared to 65 % of students in the Control group ( $\chi^2 = 2.13$ ,  $df = 1$ ,  $p < .144$ ; table 12).

Interviewed Control group students described similarities in the formats, for example, Kylie (CG-M) stated that in writing the summary report *'we had to start from the beginning, the same place where we started when we were writing up the procedure and...we had to write the results'*. In completing the summary report, many Control group students pointed out the simplicity in re-writing the labs. For Derek (CG-H), *'we already knew the results and stuff so we didn't have to re-think everything again'*. Of the control group students who thought differently about the tasks, a majority related this to distinctions between what was required in 'organization' for the two types of writing. These students attributed the difference to the format requirements between the two tasks.

Within the SWH group however, a significant number of students felt that they had to think differently when completing the two tasks and 50% of these students attributed this difference to the formats of the writing tasks. As Katy (SWH-L) explained:

I thought that I had to do a lot more with the summary lab report because I had to relate each lab together. But for the SWH, I only had to review the lab and just say what my observations were and what I learned from it.

Cara (SWH-H) also recognized distinctions between the tasks; completing the SWH fostered understanding of *'what the lab was supposed to be about...then the summary report helped me understand what all the labs were about and how that had to do with the chapter we were learning'*. Cara used the summary report to relate experiences in laboratories and also linked these ideas to the overall topic under study. Several of the survey respondents in the SWH group acknowledging differentiated thinking explained they had to 'think more during the

labs', while completing the summary report required 'remembering' and 'recall of things I'd done long before'. Alternatively, several SWH students appreciating the intellectual challenge of the summary report described that they 'connected a variety of ideas' and 'applied my knowledge' when writing. The SWH students (50%) who attributed distinctive thinking to the format described what they did, 'forming your own questions' and making 'observations' during labs and 'summarizing information' in the report.

Outcome 2. Students in both the Control group (96%;  $\chi^2 = 19.17$ ,  $df = 1$ ,  $p < .001$ ), writing results and discussion sections, and the SWH group (71%;  $\chi^2 = 11.57$ ,  $df = 1$ ,  $p < .001$ ; table 13), answering self-posed questions, considered compiling and summarizing data valuable in terms of their learning.

Miles (CG-M) explained the relevance of results and discussion sections as being essential for learning, '*you need to have that stuff because that is what happened and you have to remember it for later because that is the main part of the experiment*'. Only one surveyed Control group student did not consider writing results and discussion sections necessary for learning. A few of the surveyed SWH students who did not consider summarizing data useful pointed to confusion from the initial process of formulating their own questions, 'I didn't know what to ask' or responses pointed toward being more challenged, 'it made the lab more complicated'.

Most (71%) SWH students surveyed identified answering their own questions contributed to learning; and nearly all SWH students interviewed (17/19) described how answering their own questions improved their learning. References to personal action and elements of perceived control were found threaded throughout responses to several survey questions. Within this particular survey question, responses included 'it was up to me to

learn', 'I found out what I wanted to know', 'knew what I was looking for' and 'used my own reasoning'. For Mary (SWH-M) this had a positive motivational effect toward learning, *'it made me think more about the lab that I had done...made me want to learn more about what I had done'*. Answering self-posed questions helped Cara (SWH-H) *'understand what I was thinking in the beginning before I did the lab. It helped me understand what I was trying to figure out'*. While the format of the SWH template was unique for all students, Jerry (PR-H) described how his thinking processes changed through experiencing the novel procedure:

...having to think of your own questions was good for me because I'd never had that before and she [the teacher said] ... "Here's the lab you're going to do, think of a question that you want". And I was like, "Oh, we don't have something that we're already supposed to go and answer?...Oh, that's different". And at first I didn't like it and I was really confused, but once I kind of got used to it, it was a better opportunity because I had the questions that I wanted to be answered so I could ask that question, or what I was thinking about, and I could just go right for it in the lab and find the answer.

Approximately 52% of surveyed students completing the SWH indicated that answering their own questions changed the way they thought about the laboratory activities compared to their traditional routine. Again, nearly all (17/19) interviewed students spoke directly to this point in elaborating on how their thinking changed compared to past experiences. Contrasting SWH experiences to laboratories in junior high classes, Martha (PR-H):

it [the SWH] was like you made the questions, you answered them and then you would discuss them in class or you would compare your answers to others. And so you, it was different because you got to take more ownership...it was more of a complete feeling, you felt like you learned something instead of just writing something down in a packet to be turned in and corrected to see what you got right or wrong.

Martha (PR-H) also described how the approach she used changed her thinking:

I went into it with a certain idea of what we were going to be doing, but then when I came up with different questions. Then I branched out and I was doing different stuff than I thought I was going to be doing. I did different experiments, my observations were different from what I thought, they weren't as simple. I observed more, my results were a lot different due to my observations and conclusions.

While references to control were absent in Control group students' responses to this question, 46.8% of SWH group students attributed improvements in their learning to personal control (table 13) and 46.4% of SWH students indicated they perceived more control compared to their traditional routine in science. Comments from SWH group students often referenced personal action, as with Ken (SWH-H) who methodically described the elements indicative of his metacognition:

I got to find out what I didn't know...I think it made the experiment easier to do because I was making up what I had to find out instead of just answering the questions on the sheet. You had to think about what you already knew so you figure out what you had to ask yourself so you could find out what you wanted to know, what you needed to know.

Interestingly, students did not perceive their active role in reflective thinking as an added tax on their conceptual resources, but rather felt it made the process "easier". For Aaron (SWH-L) this improved his ability to learn, *'it was like answering my own questions was a lot easier than answering something else because I can understand it a lot better...it just brought it on a personal level...as opposed to something like the book would exactly say'*. Most interviewed students in the SWH group identified the characteristic of ownership of the task, which they found motivational and thought provoking. Students also acknowledged moving away from an authoritative source, to more independent thinking. As for Jay (SWH-M):

It made things more interesting I think because you kind of found out what you wanted to know, not what the book already knew and wants you to know. It kind of gave you some freedom, but also it was still structured...You could relate to it more. It kept you focused on things...



made me think a little harder ...you had to look at the lab and realize what you could answer. Then you can only answer certain questions. There were some things that by doing the lab you couldn't answer...it's like higher level thinking almost. You know your limitations. In the book they tell you what to think, here it is on your own...You're thinking outside of everything else.

Shane (PR-M) did not consider answering questions useful due to the uncertainty involved in formulating the questions; questions he posed were described as '*unrelated*' and '*I sort of disregarded my own question after a while*'. He did realize a change in his actions, '*I ended up having to ask myself very generalized questions at the beginning...like 'What am I going to learn? What do I expect to see that I wouldn't normally expect?'*' While Shane did not view answering his questions as beneficial, he confirmed experiencing a change in his thinking from engaging in the process and through teacher scaffolding, as the teacher would '*...tell us...you might see something different than this*', but *I'd never have guessed that in our baggie starch lab that iodine could go through the baggies, I never would have expected that because it is against all the teachings I've had before*'.

Outcome 3. More students (67%) in the SWH group described learning as they were writing ( $\chi^2 = 7.56$ ,  $df = 1$ ,  $p < .006$ ) compared to 50% of students in the Control group ( $\chi^2 = 0.00$ ,  $df = 1$ ,  $p = 1.0$ ; table 14).

Cara (SWH-H) explained, '*as I was writing I was trying to...put in the scientific word, into what I was writing and that helped me to understand what the scientific words were meaning*'. Mary (SWH-M) explained how persistence in writing was useful for her, '*if you don't understand it and you keep writing it and you keep thinking about what you're writing then it helps you a lot more*'. Learning through writing for Mary was not only about repetition, but rather the active attention and focus she applied when engaging in the task.

For Rhea (CG-H), no learning took place during writing because *'to write it out we had to know it already'*. Derek (CG-H) described learning only *'a little bit as we were writing but I...read over them and that helped me learn the most'*. He further expanded on this notion, but for him the activation of cognitive structures were separate acts, *'I think it is hard to do two things at once, especially learning and writing because those both take up a lot of thought. It is always pretty necessary to go back and read over them again'*. Students in both groups explained that the format, requiring repetition and review, were characteristics influencing their learning through writing. Interestingly, students also used these characteristics in explaining why they did not learn as they were writing because it was 'just repetition' of information they already 'knew'.

Outcome 4. Students in both the Control group (73%;  $\chi^2 = 4.55$ ,  $df = 1$ ,  $p < .033$ ) and the SWH group (85%,  $\chi^2 = 31.15$ ,  $df = 1$ ,  $p < .001$ ; table 15) perceived some level of control over their activities.

This particular question directly targeted perceptions of control over the writing activities. References to personal actions such as, 'there was freedom to do what I wanted', 'we designed', 'decided how to test', and 'I made my own choices' were in the majority (69.6%) of explanations from students in the SWH group who perceived control. Accounts categorized as format in 30.4% of SWH students' responses included, 'no one told us what to do', and 'control over how procedure was followed'. Comments related to format were also presented by students who did not sense control, 'it was an assignment' and 'felt restricted in the summary report'.

Interestingly, more students (57.1%) perceiving control in the Control group related this to the format of the task, 'none of the materials were really complex' and 'no one told us

exactly what to do', while 42.9% of respondents indicated personal action, 'prepared for the activities myself' and 'how it turned out was up to us'.

Outcome 5. Students in both the Control group (83%;  $\chi^2 = 9.78$ ,  $df = 1$ ,  $p < .002$ ) and the SWH group (95%;  $\chi^2 = 53.55$ ,  $df = 1$ ,  $p < .001$ ; table 16) indicated confidence when answering the final extended response questions.

Confidence was indicated by 50% of Control group students who pointed to personal action such as 'I had studied a lot'. Similar notes were also made by 73.3% of SWH students who felt they 'knew the material'.

One survey question targeted Peer Review group students to determine if they perceived benefit in reviewing one another's summary reports. While there was no significant difference between perceptions of value, approximately 49% of students in the Peer Review group considered the task of reviewing their peers' summary laboratory reports useful ( $\chi^2 = .024$ ,  $df = 1$ ,  $p < .876$ ). Most (10/12) interviewed students spoke directly to the value of peer reviewing, finding benefit in seeing others' interpretations for comparison to their own work. Three of these students recalled technological difficulties when submitting their reviews; however, these students still perceived benefits from the process. Of the surveyed Peer Review students, 59% highlighted the comparative value of the task and 41% indicated the task facilitated thinking or understanding. For students who did not find peer reviewing useful, approximately 33% attributed this to the format, 58% to similar content in the reports, and 8% indicated confusion.

In summarizing the major findings of Study 1, SWH group students recognized they had to think differently when completing the separate writing types and were more likely to describe how they were learning as they were writing. Students in both groups established

value in compiling and summarizing data during laboratories, perceived control in their activities, and indicated they felt confident when answering the final extended response questions.

#### Open-ended Survey Comparisons

##### *Study 2*

Results regarding Control group preferences for laboratory writing (68%) over summary report writing were significant in Study 2 ( $\chi^2 = 4.24$ ,  $df = 1$ ,  $p < .040$ ; table 17). Similar to results in Study 1, distributions of preference among students in the SWH group were balanced, 52% preferring laboratory writing with the SWH ( $\chi^2 = 0.063$ ,  $df = 1$ ,  $p < .803$ ).

Outcome 1. In agreement with Study 1 results, more students (78%) in the SWH group recognized that they had to think differently when completing the two writing types ( $\chi^2 = 22.04$ ,  $df = 1$ ,  $p < .000$ ); although, 64% of Control group students also tended to recognize distinctions in thinking when completing the two writing types ( $\chi^2 = 2.78$ ,  $df = 1$ ,  $p < .096$ ; table 18).

Outcome 2. In Study 2, a significant difference was only found among Control group students, 81% of who identified results and discussion sections as valuable in terms of their learning ( $\chi^2 = 13.44$ ,  $df = 1$ ,  $p < .000$ ). In the SWH group, 57% of students indicated value of answering self-posed questions ( $\chi^2 = 1.39$ ,  $df = 1$ ,  $p < .239$ ; table 19).

Most students in the SWH group (42.3%) who did not consider compiling and summarizing data from laboratories useful for learning linked their explanations to the quality of their questions, 'the questions were not very good', 'questions were not specific

enough', 'questions were totally off the subject', 'questions were ridiculous'. As in Study 1, approximately one-half of SWH students (47%) indicated that answering their own questions changed their thinking about laboratory activities.

Outcome 3. In agreement with Study 1 results, more students (64%) in the SWH group described learning as they were writing ( $\chi^2 = 5.71$ ,  $df = 1$ ,  $p < .017$ ) contrasted to 53% of students in the Control group ( $\chi^2 = 0.11$ ,  $df = 1$ ,  $p < .739$ ; table 20).

Outcome 4. Interestingly, another difference in outcomes between studies was found between groups' perceptions of control during the activities. A significant number, 65% of SWH group students in Study 2 perceived some level of control ( $\chi^2 = 6.06$ ,  $df = 1$ ,  $p < .014$ ). However, there was no difference in Control group students' perceptions ( $\chi^2 = 1.00$ ,  $df = 1$ ,  $p < .317$ ; table 21), 58% of these Control group students indicated a lack of control. Most responses from students in the Control group (90.5%) explained they did not sense control due to the format of the tasks, 'teacher gave all instructions' and 'told directions'.

Outcome 5. The final difference between the two studies was found in students' indicators of confidence when answering the extended response questions. Neither Control group students (61% confident;  $\chi^2 = 1.78$ ,  $df = 1$ ,  $p < .182$ ), nor SWH group students (60% confident;  $\chi^2 = 2.52$ ,  $df = 1$ ,  $p < .112$ ; table 22) differed significantly in their perceptions of confidence.

Results for the PR group were similar to findings in Study 1. Approximately 54% of students in the PR group perceived benefit from reviewing their peers' summary laboratory reports ( $\chi^2 = 0.257$ ,  $df = 1$ ,  $p < .612$ ), 59% of these students found value in comparing ideas, and 41% in stimulating their thinking or understanding. Approximately 42% of PR students

who did not find reviewing useful related this to the format of the task, 33% to similarity in content, and 25% indicated confusion or the act of reviewing was not suitable for their learning.

To highlight the main results in Study 2, more Control group students preferred laboratory writing to the summary report and found value in summarizing data, while SWH students perceived control during activities, recognized they had to think differently when completing the two writing types, and were more likely to indicate learning as they were writing.

### Discussion and Implications

Acknowledging results from the quantitative component are limited in applicability due to the small sample sizes and unique classroom contexts of Study 1 and Study 2, even so the findings were positive in providing additional information to a developing body of research with the SWH. The results from Study 1 are particularly interesting as they begin to address the question of location, that is, where in the full sequence of writing experiences (implementing the entire SWH template as described by Hand & Keys, 1999) is most conceptual gain evident? We were keen to see if evidence would be found on an assessment immediately following laboratory activities, and then after the summary task, to determine the influence from this culminating task.

Groups of students with different laboratory writing experiences did not differ on the assessment administered directly following the laboratory activities in either study. However, in performance on Test 1 conceptual questions, the interaction between sex and the type of laboratory writing in Study 1 indicated that females using the SWH had an advantage over males in the SWH group and females who wrote laboratories in a traditional format

(Control group). These findings are pertinent to calls from a recent report focused on the advancement of gender equity, asserting that it is important "to know not only what works but also what works for whom" (AAUW, 2004, p. 22). Furthermore, while the audience of summary report writing did not appear to affect performance of students in Study 1 on Test 2, findings from this assessment administered after the culminating task indicated summary report writing was significantly beneficial for students who had implemented the SWH during laboratories. The prior laboratory writing experience appeared to set the stage for achieving benefit from the summary report activity, enhancing conceptual question performance without detrimentally affecting recall question performance.

While the same finding was not repeated in Study 2, differences between the studies may provide some explanation. Direct comparison of Study 1 and Study 2 is cautioned due to these differences; however, in as much as educators tentatively compare results across a variety of educational research studies, each with distinct designs, it might be appropriate to offer a moderate comparison for explanatory purposes, with reservations made clear. The population of students in the two schools differed; notably, the experience implementing the SWH also differed between the two teachers conducting the studies, which may have been a limiting factor. In Study 2, the trend toward an interaction between sex and laboratory writing group on Test 2 conceptual question performance appears to parallel the findings in Study 1, in which the interaction was significant and SWH females ranked highest on Test 1 performance. It may be that the effect was diluted and delayed in Study 2, as the teacher became accustomed to implementing the new laboratory writing technique. Teachers implementing the SWH have found that students require approximately three laboratory experiences to become accustomed to the novel format; thus, it is likely that some time is

also necessary for the teacher to adapt and find confidence in implementing this approach. This interpretation is limited because only a subset of SWH writers was compared in maintaining the constant of summary report audience. Unfortunately, observation of the teachers was not undertaken; nevertheless, recognition of this potential variable is warranted. Further research is necessary in exploring implementation to determine if teacher experience is a factor influencing the level or quality of implementation and if varying levels of implementation are linked to student learning.

Advantage from using the SWH in Study 1 was clearly evident on the measurement (Test 2) administered after students wrote the culminating task to the same audience (the teacher), in comparing students who wrote traditional laboratory reports to students who wrote with the SWH. These results are consistent with findings from an investigation with middle school students also studying the cells topic (Hand, Wallace, & Yang, 2004), in which SWH students scored higher on conceptual questions administered after the culminating writing task, compared to students who used a traditional laboratory report. However, they also found SWH students performed better than Control group students on recall questions as well. The similarity in findings, in which conceptual learning is evident after the collective experience of SWH and summary report writing, begins to address the notion of reproducibility between students of different age levels as well as the question of location. This leads us to suggest that while there is a successful advantage in using the SWH, the full template with the synthesis task at the end is necessary to advance learning for all students.

Addressing the quantitative outcomes after the summary task immediately pointed to differences found in students' perceptions between groups. Pedagogically, the summary



report is not seen as independent from the lab activities, but rather as a culminating opportunity for students to synthesize, integrate, and relate knowledge from laboratory work together with overarching themes and information in the cell unit. In terms of the thinking required to complete the two tasks, students in the SWH group viewed the tasks as uniquely different, linked and cumulative, with benefit from consolidation. There was also an added benefit in terms of learning for SWH students in Study 1. Retaining a sense of ownership over the knowledge, focused and committed to the process, SWH students were able to construct a richer conceptual framework and understanding of cells because the second writing task was viewed as requiring them to do essentially this. They viewed the purpose of the summary report as a form of focusing on the big ideas and explaining these together. These students reported integrating understanding of each laboratory in the process of writing their summary reports, the format of which they felt required them "to relate each lab together" as well as the unit under study.

On the other hand, Control group students tended to view the two tasks as linked, but repeated, essentially one continuous task. For these students the process of writing the summary report largely consisted of compiling information they already had, which did not require revision in thinking or restructuring of their writing. Our recent research (Hand, et al., 2004) has provided some evidence that further learning gains on conceptual questions were achieved by students completing two different linked writing tasks compared to students completing only one task. The present studies suggest that the degree of linkage perceived among the tasks, perhaps resulting from the nature of the tasks, may influence the cumulative learning benefits. This suggests an important pedagogical implication in using writing tasks, in that whole class discussions should be conducted to elicit from students their

ideas of distinctions in the format requirements of the writing tasks prior to writing.

Discussions should make tacit the summary reports' role for connection and application, extending beyond a role of compiling and summarizing information.

The differences between the two groups revealed in students' perceptions (both Study 1 and Study 2) and performances (Study 1) are critical in terms of the construction of understanding. It appears as though students in the control group were not building knowledge as well as the SWH students, even when provided similar opportunities. In both studies, distinctions were present in students' perceptions between groups, SWH students were more likely to report different thinking was required by the two tasks and more frequently described learning as they were writing compared to Control group students. Attention to format, that is the structure of the writing tasks, was the category most often cited by students in explaining why they were learning as they were writing. In relating the structural component, findings from a past study (Hand et al., 2004) investigating the role of the sequence of planning activities within a writing experience, provides some explanation. Comparing initial and delayed planning sequences, the results indicated that students who had planning experiences outright were more focused on organization and how to best represent relationships between concepts, having worked out the task goals and conceptual explanations during the prior planning process. While the revision process was not the focus in the present study, laboratory writing with the SWH might have served as a more appropriate guide for planning the summary task. The scaffolded nature of the SWH approach is different to that of the traditional laboratory report. The function of the SWH activities, such as posing questions, identifying claims, and providing evidence, is to build a scientific argument. In contrast, the function of hypotheses, results and discussion is to

report an experiment. Thus, the advantage SWH students in Study 1 appeared to have over Control students on Test 2 measures was most likely influenced by the function of the laboratory writing. The ability of most SWH students to recognize distinctions between the two tasks might also be explained by the function of their SWH writing, that is, building a scientific argument was seen as distinct from integrating a series of findings in a summary report.

Lastly, differences in students' metacognitive awareness indicators such as perceived control and confidence were not too surprising. In Study 2, SWH students were more likely to perceive they had control than students writing traditional laboratory reports, matching what is expected from engaging in self-directed, inquiry activities with the SWH. The findings indicate these students adopted a sense of "executive control" in actively constructing their own meanings through completing laboratory activities (Yore, 2000, p. 105), which we argue was promoted by the metacognitive scaffolding prompts in the SWH template. However, both groups in Study 1 reported perceiving control when asked directly. All students were engaged in the process of inquiry during their investigations and constructivist practices were employed in scaffolding students' questions or hypotheses, and experimental designs. A significant number of Control group students reporting perceived control over activities might have resulted not only from the nature of the inquiry activities per se, but also from an inability of the teacher in Study 1 to conduct a "true control" experience, pedagogically, for students in the traditional writing group. If this was actually the case, it suggests that there may be a trade-off between implementation experience and representation of a true control group, particularly important in considering design of future research studies with constructivist teachers.

Similarly, confidence indicators could be reflections of the two school settings (suburban and urban), the composition of students in the classroom, as well as the implementation experience of the teachers. Study 1 students were advanced tracked students, and as such, it is not surprising that both groups of students reported confidence in their learning. The lack of significant difference in confidence reported by either control group or SWH group students in Study 2 might have resulted from a greater range of student abilities represented in the regular course and possibly reflected the level of confidence the teacher had in implementing the SWH for the first time.

Findings from the present studies regarding the audience component were a bit perplexing. Quantitative outcomes from groups who had similar laboratory writing but wrote to different audiences (SWH compared to Peer Review) did not differ in either study, indicating audience was not an important factor. This was surprising in that two earlier studies suggested the role of the audience was important for learning by encouraging a need for translation of technical language. One of these studies involved seventh-grade students writing textbook explanations on the topic of cells for their same-aged peers in another school (Hand, Wallace, & Yang, 2004). The second study included tenth-grade students explaining biotechnology concepts to younger, seventh-grade students (Hand, Hohenshell, & Prain, 2004). The inability to elucidate an audience effect in the present study is likely influenced by the small sample sizes; however, age and the developmental appropriateness of the topic may also be important factors. For example, the high school students in the present study are likely to be more familiar with cellular concepts than middle school students; thus, we might expect the probability for the existence of naïve conceptions would be greater for younger students. Students with less sophisticated understanding might have a better

opportunity to benefit from writing as there is a greater chance to realize gaps in knowledge during writing and then gain from formulating conceptual links and consolidating topic ideas in the writing, which was likely the case for middle school students. Similarly, we might expect high school students had more to gain in composing explanations of biotechnology to a younger audience because their exposure to this particular topic might be less sophisticated than a more common curricular thread, such as the cells topic in the present study. While these arguments may be plausible, additional research is needed, targeting different types of tasks, writing audiences, and task sequences with diverse student populations, attending to the nature of the conceptual topic under study as well as the development and age of participants. Prudence is in order with regard to students' prior experience with the topic so as to maximize students' potential for using writing for learning and demonstrating resultant understandings; to this end, assessments should be composed of challenging conceptual measures, which are thought to best reflect the quality of learning served by writing to learn strategies.

## CHAPTER 5: GENERAL DISCUSSION

In this section, the major findings and limitations of the investigations in Chapter 3 and 4 are discussed collectively in addressing the questions that framed the work in this dissertation. The main implications that arise from these studies for practice are also presented within the relevant questions. First, one caveat is in order related to the context in which these studies took place. While particular writing tasks and experiences were the focal points of the investigations, the manipulated independent variables, any findings must be interpreted as situated in a larger context, consisting of teachers who were informed by and embraced constructivist learning theories, and in doing so attempted to provide "full writing strategy support" introduced by Klein (1999, p. 260). These studies therefore, did not isolate the writing tasks. Rather, writing was integrated with other learning modes and support strategies, such as with the processes of inquiry and argumentation. I contend that these processes were also scaffolded by the writing tasks, which applied to developing explanations concerning biotechnology topics in the first study (Chapter 3) and the topic of cells in the second set of studies, through use of the SWH (Chapter 4). As such, these findings were limited to two biology topics.

### Research Questions

Integrating the investigations when appropriate, the main findings relevant to the six key questions presented in Chapter 1 are summarized in this section.

#### Question One

Concerning the effect of different planning experiences prior to writing addressed in Chapter 3, the type of planning does not appear to matter in terms of student learning, as

performances on test measures were not different between groups. As with Kellogg (1987), outright planning did have a positive effect on writing quality. Pre-planning experiences also contributed to higher quality science content explanations in the textbook task. This indicates that pre-planning experiences were important for more accurate and complete idea representations as well as textual coherence, but *when* this planning occurred did not matter in contributing to students performance on tests. However, we did not attempt to identify which type of strategy individual students preferred, as did Galbraith (1992), which leaves the question as to whether or not students would benefit from engaging in strategies to which they are not accustomed and may not even prefer.

More students with pre-planning experiences felt prepared to succeed in writing, implying that more students may prefer these early structuring experiences to the persistent and continuous expression of ideas advocated for writing by Galbraith (1992). Because no differences were detected in learning gains as a result of either strategy, no claim can be made as to which cognitive model best served discovery. However, the cognitive processes they did report using were in line with those explained in the models. As with Keys (2000), students appeared to use different mechanisms during the writing processes, which were linked to the type of planning sequence they experienced. Specifically, students in the planned group reported they engaged in more backward searches of their text, adopting the rhetorical goal of communicating to their audience and reordering their ideas in attending to the needs of this audience, cognitive processes that Klein (1999) argued typifies those in the model proposed by Flower and Hayes (1981). In contrast, students in the delayed-planned group, while still attending to their rhetorical goal focused on the audience, tended to follow the momentum in their initial experience to get the words out in expressions of "utterances"

in text, typical of Galbraith's model (1999). For this, they were essentially focused on expanding their explanations by adding more words to their text and in this occupation were less likely to reorganize the content within the text. Guided planning writing experiences may be one support mechanism to help students attend to important rhetorical and content goals, which may free resources for attention to composing (Kellogg, 1987), and also consolidation of science concepts represented. Interestingly, different mechanisms employed did not appear to enhance or deter learning, and while these findings should be taken as exploratory, they do suggest that planning, regardless of timing, is important.

#### Question Two

While experiencing multiple writing will not necessarily lead to more learning (Bangert-Drowns, Hurley, & Wilkinson, 2004), the quantitative results (Chapter 3) provide more empirical support implied by previous studies (Hand, Prain, & Wallace 2002), suggesting that students who complete more than one writing task have an advantage compared to students writing only once or not at all. Specifically, students completing two tasks performed better than students completing one task (Chapter 3), and this effect increased over time after the second writing experiences and on a delayed test measure. In the opposite direction, but an equally positive finding was that when a sex gap existed, multiple writing experiences appeared to help close that gap (see question 6 for decreasing effect sizes related to students performance on conceptual questions). These findings suggest that there is likely some cumulative benefit gained from engaging in multiple writing tasks. Such experiences should be strategically chosen so as not to result in needless repetition. Also, they should be reserved for more conceptually demanding tasks, to match the instruction (student-centered writing experiences) with the cognitive thinking levels the tasks



elicit and are expected to help develop (Applebee, 1984). While these studies begin to provide further evidence for learning through writing tasks, there is still a need for more research on which linked tasks and sequences maximize learning of particular science topics and concepts.

In completing a multiple series of tasks (Chapter 4), when different types of tasks are used, students reported indicated that they recognize a distinction in thinking is required by the different types of tasks. However, this recognition depended on the use of non-traditional laboratory writing tasks (the SWH), as students in the SWH group were more likely to identify differences in thinking between the laboratory writing and the summary report writing, and these results match those found with seventh grade students (Gunel, Omar, Grimberg, & Hand, 2003). In recognizing differences in task demands, students are in a better position to engage in the thinking practices targeted by the tasks, which may influence what they do while composing and the learning they experience as a result.

### Question Three

The question addressed in Chapter 4 as to whether learning would result from using a modified laboratory template (SWH) compared to writing in a more traditional format was approached on two levels, in terms of timing, immediately following a series of laboratory experiences, and after constructing a summary report of those experiences. The second level addressed the question in terms of students' perceptions of learning. Positive results, indicating there was a performance advantage in using the SWH, were found after summary report writing, but these findings were limited to one comparison (Study 1). Similar results have been reported with seventh-grade students (Hand, Wallace, & Yang, 2004), as

significant differences between SWH and control groups were found on an assessment after the full SWH sequence, that is after a consolidating writing task.

To highlight specifics, no differences between traditional and SWH groups' test performances were detected on the assessment immediately following laboratory writing in either Study 1 or Study 2, although SWH females appeared to have an advantage over SWH males and control females in Study 1. A difference in test performance between SWH students and traditional report writing students was detected after writing the summary report; however, this result was only found in Study 1. However, SWH students in both Study 1 and Study 2 were more likely to report learning as they were writing compared to control group students.

Since comparisons indicated that the audience of the summary report did not appear to influence performances, two additional factors concerning timing of the assessment and the teachers in the studies offer possible explanations for these findings. For example, the factor of timing revealed in questioning research (ex. Andre, 1990) may be important, as students may need more time engaging with complex material. The consolidating task is not only another means, but also provides more time for students to integrate these concepts into existing conceptual structures. The SWH students, better positioned in their thinking about the concepts by their scaffolded laboratory writing experiences, might have been at some advantage in writing the summary report and on the subsequent assessment. This might explain why differences between SWH and control groups were only detected on the second assessment, after the summary report writing. While the populations between the two studies differed, the teachers also differed in terms of their years of teaching and experience implementing the SWH. Thus, more research in this direction (Omar & Gunel, 2004; Omar,

Hand, & Greenbowe, 2002) is also needed concerning the teacher's role in scaffolding with the SWH.

#### Question Four

When integrating the results from these investigations, the findings addressing the question related to audience, at best, were mixed. The mixed findings might relate to differences in the actual audiences for writing, seventh-grade students (Chapter 3) and peers (Chapter 4). Flower and Hayes (1980) suggested that the effectiveness of the audience in the task requires the writer's attention and intention, "a detailed analysis of the reader may have little impact until it is transformed into goals for affecting the reader or into a simulated reader response to the text" (1984, p. 155). Adoption of this intent was clear in students' (Chapter 3) comments concerning the value of translating language for younger students helped in constructing understanding for themselves. Flower and Hayes (1984) suggested such benefits depend on the writer's recognition of an interaction existing between communicating to an audience and translating to the self.

Comparisons in the second investigation (Chapter 4) did not result in quantitative differences between students writing to their peers and students writing to the teacher in terms of learning. And on the survey, only half of the students in both studies perceived benefit in writing to their peers. Students in Chapter 3 and Chapter 4 appeared to differ in the degree to which they adopted the audience for their rhetorical goal. However, caution is warranted in attempting to integrate the outcomes from the two investigations not only due to different audiences, but also different mechanisms used to construct the writing (an environmental variable). The students writing a summary report to peers submitted these reports using an internet website; thus, this potential technological anomaly cannot be

separated out. Additionally, students writing to their peers may not have considered the audience consisted purely of their peers, as reports were submitted to the teachers as well.

Positive responses from students interviewed in Study 1 (Chapter 4) and students writing to seventh-graders (Chapter 4) affirm Lemke's (1990) suggestion that writing to peers and different audiences helps students "break the rules" that are implied by the stylistic norms of authoritative scientific discourse (p. 133). Such translation activity may help students break through these norms characteristic of science language, which might otherwise stunt learning and impede communication. Students not only attach personal meanings to the language of science, but also in re-representing this language, particularly in writing to a younger audience, they re-humanize it "as they communicate it" (p. 133).

Points from Halliday (1993b) related to syntactic ambiguity and the grammatical metaphor are particularly relevant here, not only in the challenge to understand science writing involved in translating for self, but also in trying to represent that understanding in translating for an audience. He explained that writers might not realize characteristics of scientific language that contribute to complexity and difficulty until they make an attempt to rewrite in their own words. This suggests that in adopting the rhetorical goal of effectively communicating to another audience (Flower & Hayes, 1980), students may have found some difficulty in expressing and representing their understanding for this audience, not only in simplifying vocabulary for younger audiences (Chapter 3) and perhaps for peers (Chapter 4), but also in reconstructing the grammar appropriate for those audiences. In observing students (Chapter 3) as they were negotiating the task demands, comments were suggestive of this aspect, but this was not targeted in the study, nor was it formally recorded; thus, this hypothesis requires more research before a claim of this sort can be made or supported.

However, this is likely an important aspect, which might be further explored in textual analysis of revisions and targeted directly by interview questions in future studies.

Galbraith (1992) reminded readers of the limitations of self-reporting used in his own study, in that perceptions of learning cannot be taken to indicate learning has occurred and the limitations also apply here regarding students' responses. On the optimistic side, students' (Chapter 3) accounts of the value of writing to a younger audience were detailed descriptions of the powerful potential for writing to serve learning in science. While attempts to address the audience factor did not result in a definitive answer, more research is nevertheless warranted concerning its role in the writing process and its motivational potential to promote learning.

#### Question Five

Results concerning the question addressing the potential factor of sex in performance differences were also mixed in that males appeared to have an advantage from initial writing experiences (Chapter 3), while females appeared to benefit early on from using the SWH (Study 1, Chapter 4). Interestingly, these advantages disappeared with subsequent writing experiences. In the first study (Chapter 3), this advantage disappeared over time, with a second writing experience. Specifically, there was a medium effect (.73) with males performing better than females on conceptual questions in the assessment directly following the textbook explanation task; but this effect decreased (.13) after a subsequent news article task and essentially disappeared (.06) on the assessment after an eight-week delay. Performance differences related to sex found in Chapter 4 were discussed in more detail previously (Question 3).

Taken together, these results agree with Rivard and Straw (2000), who found that females benefit from experiences integrating both opportunities for negotiation through discussion and writing. In Study 2 (Chapter 4), SWH females appeared to have an advantage over SWH males in terms of performance on conceptual question items; however, the difference was only detected on the assessment administered after the summary report writing. Since potential differences may exist between males and females, including the factor of sex in quantitative and qualitative analyses is warranted. Additional research could explore elements of the writing process that might relate to sex to determine if there are distinctions in terms of the approach or strategies used, which might better inform how writing-to-learn experiences can be utilized to benefit both males and females.

#### Question Six

Students identified both social experiences and particular task requirements as important components contributing to their learning. In addition to the value of writing to a younger audience that was previously discussed in Question 4, comments from these students (Chapter 3) also indicated they perceived opportunities to share and discuss their emerging ideas were valuable in helping them navigate the demands of the task. Such experiences promoted confidence in meeting challenging task requirements, such as translating scientific terms for their younger audience, which helped consolidate their own understanding. The assertion that socially negotiated experiences are critical support mechanisms for learning through writing is in agreement with findings from Rivard and Straw (2000). These findings also agree with others who have suggested that integrating collaborative discourse experiences, such as talk and writing, are essential supportive components in promoting students' thinking, reasoning, conceptual change, reasoning, and inquiry processes (Fellows,

1994; Keys, 1994; Mason, 1998; Roth & Roychoudhury, 1993). Thus the perceived value of these social interactions combined with writing to meaningful audiences reported by college students (Chinn & Hilgers, 2000) were also reflected in these high school students' comments (Chapter 3).

Past studies with the SWH (Hand, Wallace, & Yang, 2004) have highlighted the benefit SWH students experienced in answering self-posed questions, which the authors argued helped student make sense of language and construct personal meanings from laboratory experiences. These results were not confirmed in the present study, however this might have been due to a limitation from the questioning language used on the survey and during the interviews. The survey is clearly a work in progress, as items need to be reformulated to help target differences indicated by previous studies. For example, a question should directly compare the value of constructing hypotheses to self-posed questions and the phrase "answering your own questions" should be reserved for a separate question. Additionally, more information would be useful to directly assess nature of science content, in determining whether groups differ in their understanding of the meanings of terms that represent scientific processes of inquiry and argumentation (hypothesis, claims, evidence). The SWH is a different type of scaffold compared to the traditional laboratory report, in that thinking processes are directly targeted by the SWH in questions that stimulate individual thinking and reflection, and prompts that encourage social negotiation of experiences, through interactions such as comparing ideas to peers and findings in other resources. As such, more research is needed to further characterize the role of the SWH as a scaffolding tool for laboratory writing to tease out which elements in particular stimulate certain cognitive processes. These could then be compared to those of other laboratory

writing types, such as the traditional report. I suspect, for example, that the SWH is a better scaffold of scientific processes, particularly related to competencies necessary for experimental design. However, because only one conceptual question targeted this skill, more research is needed to support this hypothesis. Such distinctions might lead to further characterize essential elements of what Klein (1999) termed as "full writing strategy support" (p. 260).

### General Conclusions

In summary, conservative interpretation of these results is warranted, as the findings are limited in generalizability to larger populations since these studies were conducted in classrooms with a limited number of students. Collectively, the findings indicate that multiple writing tasks provide cumulative benefits and students using non-traditional writing-to-learn experiences are at an advantage compared to students with traditional writing experiences. In Chapter 4, students using a non-traditional, SWH template to scaffold their inquiry laboratory writing, performed better than students writing in a conventional format (control group) on an assessment administered following a summary report in which they consolidated their understandings of the laboratory concepts. In the planning study (Chapter 3), the delayed-planning that students experienced in producing their first drafts outright mimicked the traditional writing routine common in science classrooms, in which little to no guidance is provided to assist students in structuring their writing. Students in the planned group, participating in a series of activities to structure their writing initially, outperformed delayed planning students in effectively communicating their understanding of science content in their final drafts. Both groups eventually had planning experiences and since no differences in test performances were detected, planning support appears to be an essential



component for writing to serve student learning. Such planning strategy support for writing is provided through constructive scaffolding experiences.

Scaffolded writing experiences result in learning for students. Important scaffolding includes both choice of particular writing tools and strategies, as with the SWH and the planning experiences. Important scaffolding also includes teacher guidance in structuring activities that promote socially interactive experiences during which students navigate and discuss the various demands and dimensions of their writing tasks. Such negotiated experiences are in line with pedagogical recommendations from the interactive-constructivist position (Yore, 2001). The cognitive work in writing requires both the social component and individual student action; thus, social interactions were paramount for students in recognizing the social world as a knowledge resource and personally capitalizing on it.

The findings also point to the importance of providing multiple writing experiences. This is important because students are able to recognize different task demands require different levels of thinking. Such consciousness in the requirements of the task may increase the likeliness that different cognitive mechanisms are engaged in learning through writing. Providing more writing experiences also appears to be important in moving toward equity, which is not equality but rather equal opportunity to learn (Michael Scott, personal communication), as the benefits from completing multiple writing tasks appeared to be realized by all students, regardless of sex.

#### Direction for Future Research

In addition to those mentioned above, more research is in order to determine how writing-to-learn strategies in science apply to learning beyond the science classroom. For example, some students articulated the planning experiences would be useful to apply

elsewhere, and future questions could probe this issue further, in asking students to identify whether or not they realized such an extension, to describe how particular experiences might be adapted, and in what areas they see these experiences as most relevant. The last set of questions, following Flower and Hayes (1984) and Newell (in press), relate to the illustration in Chapter 1 (Figure 1) in the introduction. It would be useful to explore relationships between conceptual organization, writing processes, and learning. For example, does the more a student understand, represented by a complex concept map, with a large number of appropriate connections, constrain or enhance their ability to express that understanding in a linear product? Do these baseline maps influence the processes the writers choose in attempting to represent this understanding, both when content and rhetorical goals are set, and when they are left more open?

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## APPENDIX A. INFORMED CONSENT LETTER (CHAPTER 4)

Principal Investigator: Brian Hand

Modified Informed Consent Letter for the Project: A Comparison of a Traditional Instructional Approach with Writing to Learn Approaches using a Science Writing Heuristic

Dear Students:

We are conducting research to determine how writing tasks can promote learning Biology concepts. The information obtained from this study should help us improve instruction in science classes.

The study will be conducted during Unit II, and data will be collected from now until the end of the semester. The objectives will be the same for all sections as will be the time frame expected to complete the assignments. You will not be required to complete extra work. Instead of the traditional laboratory write up, you will have a slightly modified writing assignment to complete. Your grade is not likely to change as a result of participation in this study.

Your section has been randomly chosen to participate. If you do not wish to participate in this study, please see your instructor. You will still need to complete all of the assignments.

All data from this study will be held in the strictest of confidence. Your name will not be associated with the data we collect, instead a number will be used, and identifiers will be removed June 6, 2003. Any questions you have about this experiment will be answered to your complete satisfaction. You are free to withdraw at any time without prejudice; doing so will not adversely effect your evaluation.

Thank you for your attention.

## APPENDIX B: SURVEY CODING TABLES (CHAPTER 4)

Table 11. Study 1 Comparison of Students' Preferences for Writing types: Laboratory Writing vs. the Summary Report.

Control Group					SWH Group				
	$\chi^2$	<i>df</i>	<i>p</i>	N		$\chi^2$	<i>df</i>	<i>p</i>	N
	3.522	1	.061	23		.258	1	.611	62
Laboratory				16	SWH laboratory				33
<u>Student Responses:</u>			(%)		<u>Student Responses:</u>			(%)	
Hands on			16.7		Hands on			8.6	
Format			77.8		Format			60.0	
Shared			0		Shared			2.9	
Knowledge			5.5		Knowledge			28.6	
Summary Report				7	Summary Report				29
<u>Student Responses:</u>			(%)		<u>Student Responses:</u>			(%)	
Hands on			0		Hands on			0	
Format			40		Format			56.7	
Shared			0		Shared			0	
Knowledge			60		Knowledge			43.3	

Note. Sample size less than the total collected (SWH  $n = 65$ ) resulted from a few students not indicating preference for either category in their response. Wording on the questionnaire differed slightly between groups:

CG: You have had 2 different forms of writing during the cell unit, writing up each lab (hypothesis, procedure, results/discussion) and the Summary Laboratory Report. Which did you like best? Why?

SWH: You have had 2 different forms of writing during the cell unit, the Science Writing Heuristic (during labs) and the Summary Laboratory Report. Which did you like best? Why?

Table 12. Study 1 Comparison of Students' Questionnaire Responses to, 'Were they [Laboratory Writing and the Summary Report] the same for you or did you have to think differently when completing them? How?'

Control Group					SWH Group					
	$\chi^2$	$df$	$p$	N		$\chi^2$	$df$	$p$	N	
Yes, same	2.130	1	.144	23	Yes, same	25.000	1	.000	64	
				8						12
	<u>Student Responses:</u> (%)					<u>Student Responses:</u> (%)				
	Same content			50		Same content			57.1	
	Format			50		Format			14.3	
	Thinking			0		Thinking			28.6	
No, different				15	No, different				52	
	<u>Student Responses:</u> (%)					<u>Student Responses:</u> (%)				
	Same content			11.8		Same content			6.0	
	Format			64.7		Format			50.0	
	Thinking			23.5		Thinking			44.0	

Note. Sample size for the SWH group was less than the total collected (SWH n = 65) because one response did not clearly indicate either category.

Table 13. Study 1 Comparison of Students' Perceptions of the Value of Compiling and Summarizing Data from Laboratories in Facilitating Learning.

Control Group					SWH Group					
	$\chi^2$	$df$	$p$	N		$\chi^2$	$df$	$p$	N	
Yes	19.174	1	.000	23	Yes	11.571	1	.001	63	
				22						45
	<u>Student Responses:</u> (%)					<u>Student Responses:</u> (%)				
	Control			0		Control			46.8	
	Thinking			58.8		Thinking			44.7	
	Comparing			5.9		Comparing			2.1	
	Format			35.3		Format			6.4	
No				1	No				18	
	<u>Student Responses:</u> (%)					<u>Student Responses:</u> (%)				
	Prediction			0		Wrong question			33.3	
	Knew			0		Knew			27.8	
	Not suitable			100		Not suitable			38.9	

Note. Sample size less than the total collected (SWH  $n = 65$ ) resulted from researchers unable to classify two responses under either category. Wording on the questionnaire differed slightly between groups:

CG: Did writing the results and discussion help you learn? How?

SWH: Did answering your own questions on the SWH help you learn better? Why?

Table 14. Study 1 Comparison of Students' Questionnaire Responses to, 'Were you learning as you were writing? Please explain'.

Control Group					SWH Group				
	$\chi^2$	$df$	$p$	N		$\chi^2$	$df$	$p$	N
Yes	.000	1	1.0	22	Yes	7.563	1	.006	64
				11					43
	<u>Student Responses:</u> (%)					<u>Student Responses:</u> (%)			
	Thinking					Thinking			
	New ideas					New ideas			
	Format					Format			
No				11	No				21
	<u>Student Responses:</u> (%)					<u>Student Responses:</u> (%)			
	Confusion					Confusion			
	Learn other ways					Learn other ways			
	Knew					Knew			

Note. One response was unable to be classified under either category resulting in a sample size less than the total collected for the SWH group ( $n = 65$ ).

Table 15. Study 1 Comparison of Students' Perceptions of Control during Activities.

Control Group					SWH Group				
	$\chi^2$	$df$	$p$	N		$\chi^2$	$df$	$p$	N
Control	4.545	1	.033	22	Control	31.154	1	.000	65
				16					55
	<u>Student Responses:</u> (%)					<u>Student Responses:</u> (%)			
	Personal Action					Personal Action			
	Format					Format			
No control				6	No control				10
	<u>Student Responses:</u> (%)					<u>Student Responses:</u> (%)			
	Confusion					Confusion			
	Format					Format			

Note. One response was unable to be classified under either category resulting in a sample size less than the total collected for the Control group ( $n = 23$ ).



Table 16. Study 1 Comparison of Students' Confidence when Answering Essay Questions.

Control Group				SWH Group			
$\chi^2$	<i>df</i>	<i>p</i>	N	$\chi^2$	<i>df</i>	<i>p</i>	N
9.783	1	.002	23	53.554	1	.000	65
Confident			19	Confident			62
<u>Student Responses:</u>		<u>(%)</u>		<u>Student Responses:</u>		<u>(%)</u>	
Personal Action		50.0		Personal Action		73.3	
Format		50.0		Format		26.7	
Not confident			4	Not confident			3
<u>Student Responses:</u>		<u>(%)</u>		<u>Student Responses:</u>		<u>(%)</u>	
Confusion		100		Confusion		33.3	
Format		0		Format		66.7	

Note. The prompt for all students read, 'How did you feel when answering the essay questions this last time, were you confident?'

Table 17. Study 2 Comparison of Students' Preferences for Writing Types: Laboratory Writing vs. the Summary Report.

Control Group					SWH Group				
	$\chi^2$	<i>df</i>	<i>p</i>	N		$\chi^2$	<i>df</i>	<i>p</i>	N
Laboratory	4.235	1	.040	34	SWH laboratory	0.063	1	.803	64
				23					33
Student Responses: (%)					Student Responses: (%)				
Hands on					Hands on				
Format					Format				
Shared					Shared				
Knowledge					Knowledge				
Summary Report				11	Summary Report				31
Student Responses: (%)					Student Responses: (%)				
Hands on					Hands on				
Format					Format				
Shared					Shared				
Knowledge					Knowledge				

Note. Sample size less than the total collected (Control group  $n = 36$ ; SWH  $n = 65$ ) resulted from students not indicating preference for either category in their response. Wording on the questionnaire differed slightly between groups:

CG: You have had 2 different forms of writing during the cell unit, writing up each lab (hypothesis, procedure, results/discussion) and the Summary Laboratory Report. Which did you like best? Why?

SWH: You have had 2 different forms of writing during the cell unit, the Science Writing Heuristic (during labs) and the Summary Laboratory Report. Which did you like best? Why?

Table 18. Study 2 Comparison of Students' Questionnaire Responses to, 'Were they [Laboratory Writing and the Summary Laboratory Report] the same for you or did you have to think differently when completing them? How?'

Control Group					SWH Group					
	$\chi^2$	<i>df</i>	<i>p</i>	N		$\chi^2$	<i>df</i>	<i>p</i>	N	
Yes, same	2.778	1	.096	36	Yes, same	22.043	1	.000	69	
				13						15
	<u>Student Responses: (%)</u>					<u>Student Responses: (%)</u>				
	Same content					Same content				
	Format					Format				
No, different	Thinking				No, different	Thinking				
				23					54	
	<u>Student Responses: (%)</u>					<u>Student Responses: (%)</u>				
	Same content					Same content				
	Format					Format				
	Thinking					Thinking				

Note. Sample size for the SWH group less than the total collected (SWH  $n = 72$ ) was due to a few responses not clearly indicating either category.

Table 19. Study 2 Comparison of Students' Perceptions of the Value of Compiling and Summarizing Data from Laboratories in Facilitating Learning.

Control Group					SWH Group				
	$\chi^2$	<i>df</i>	<i>p</i>	N		$\chi^2$	<i>df</i>	<i>p</i>	N
Yes	13.444	1	.000	36	Yes	1.389	1	.239	72
				29					41
	<u>Student Responses:</u> (%)					<u>Student Responses:</u> (%)			
	Control		0			Control		47.4	
	Thinking		51.7			Thinking		34.2	
	Comparing		3.4			Comparing		0	
	Format		44.8			Format		18.4	
No				7	No				31
	<u>Student Responses:</u> (%)					<u>Student Responses:</u> (%)			
	Prediction		33.3			Wrong question		42.3	
	Knew		0			Knew		26.9	
	Not suitable		66.7			Not suitable		30.8	

Note. Wording on the questionnaire differed slightly between groups:

CG: Did writing the results and discussion help you learn? How?

SWH: Did answering your own questions on the SWH help you learn better? Why?

Table 20. Study 2 Comparison of Students' Questionnaire Responses to, 'Were you learning AS you were writing? Please explain'.

Control Group					SWH Group				
	$\chi^2$	<i>df</i>	<i>p</i>	N		$\chi^2$	<i>df</i>	<i>p</i>	N
Yes	.111	1	.739	36	Yes	5.714	1	.017	70
				19					45
	<u>Student Responses:</u> (%)					<u>Student Responses:</u> (%)			
	Thinking		27.8			Thinking		27.0	
	New ideas		0			New ideas		16.2	
	Format		72.2			Format		56.8	
No				17	No				25
	<u>Student Responses:</u> (%)					<u>Student Responses:</u> (%)			
	Confusion		0			Confusion		10.5	
	Learn other ways		33.3			Learn other ways		57.9	
	Knew		66.7			Knew		31.6	

Note. Two responses from students in the SWH group were unable to be categorized resulting in a sample size less than the total collected (SWH n = 72).

Table 21. Study 2 Comparison of Students' Perceptions of Control during Activities.

Control Group					SWH Group				
	$\chi^2$	<i>df</i>	<i>p</i>	N		$\chi^2$	<i>df</i>	<i>p</i>	N
Control	1.000	1	.317	36	Control	6.061	1	.014	66
				15					43
	<u>Student Responses:</u> (%)					<u>Student Responses:</u> (%)			
	Personal Action					Personal Action			
	Format					Format			
No control				21	No control				23
	<u>Student Responses:</u> (%)					<u>Student Responses:</u> (%)			
	Confusion					Confusion			
	Format					Format			

Note. Sample size less than the total collected (SWH *n* = 72) was due to responses not clearly indicating either category.

Table 22. Study 2 Comparison of Students' Confidence when Answering Essay Questions.

Control Group					SWH Group				
	$\chi^2$	<i>df</i>	<i>p</i>	N		$\chi^2$	<i>df</i>	<i>p</i>	N
Confident	1.778	1	.182	36	Confident	2.522	1	.112	67
				22					40
	<u>Student Responses:</u> (%)					<u>Student Responses:</u> (%)			
	Personal Action					Personal Action			
	Format					Format			
Not confident				14	Not confident				27
	<u>Student Responses:</u> (%)					<u>Student Responses:</u> (%)			
	Confusion					Confusion			
	Format					Format			

Note. Sample size less than the total collected (SWH *n* = 72) was due to responses not clearly indicating either category. Prompt for all students read, 'How did you feel when answering the essay questions this last time, were you confident?'

### Criteria Outline Rubric for Summary Lab Report

The purpose of your Summary Lab Report is to summarize the learning that occurred from your participation in the six labs during the cell unit and expand on these ideas from the labs by including information from external sources (research and reading). You also need to describe how you learned the information (what you did during your procedures).

In your Laboratory Report Summary, you will earn points for including the following:

#### 1. Eukaryotic Animal Cell (cheek)

#### 2. Eukaryotic Plant Cell (onion)

Criteria	Points	Score
Identify 2 types of eukaryotic cells & provide examples for each	2	
Describe procedure (comparison under microscope 430x)	1	
Identify 3 similarities between the eukaryotic cells that you observed under the magnification limits of your microscope (cell membrane, nucleus, cytoplasm)	3	
Identify similarities between the eukaryotic cells that you may not have observed due to the limitations of your microscope (nuclear membrane, ribosomes, membrane bound organelles: mitochondria, Golgi apparatus, ER)	3	
Explain differences between the eukaryotic cells that you observed under the magnification limits of your microscope (shape/organization, cell wall, large vacuole, vesicles/granules)	3	
Explain other differences between the eukaryotic cells that you may not have been able to observe directly from viewing under the microscope (centrioles, lysosomes)	2	
	14	

#### 3. Diffusion of Potassium Permanganate (KMnO<sub>4</sub>)

Criteria	Points	Score
Demonstrates understanding of the terms kinetic energy, diffusion, concentration gradient, solute, solvent, molecules	6	
Identifies the factor tested that effects diffusion and describes how the factor was tested (temperature, 2 beakers used with different temps of water)	2	
Explains the results of the test (solute diffusion rate increases with temp)	2	
	10	

### Osmosis & Diffusion through a Selectively Permeable Membrane

#### 4. Osmosis (Starch Solution, Iodine, and Baggie)

#### 5. Salt Solution vs. Water with Potato

#### 6. Karo Syrup vs. Water with Egg

Criteria	Points	Score
Defines osmosis ( <b>water moves down</b> concentration <b>gradient</b> through <b>selectively permeable membrane</b> )	4	
Defines selectively permeable (some in some out)	1	
Explains the procedure of the 3 labs:		
1. <b>starch</b> solution in <b>baggie</b> representing <b>selectively permeable membrane</b> , <b>iodine</b> added to <b>water</b>	5	
2. <b>Equal</b> volumes of salt solution & <b>water</b> , <b>equal potato</b> slices; <b>measurement</b> recorded	6	
3. <b>Vinegar</b> used to <b>decalcify egg</b> added to equal volumes of <b>syrup</b> & <b>water</b> ; <b>measurement</b> recorded	5	
Describe the results of each of the 3 labs and use scientific terminology to explain these results (explain the evidence you have for your conclusions):		
1. <b>Iodine diffused</b> from <b>high [ ] outside</b> bag to <b>low [ ] inside</b> ; evidence is the <b>starch</b> solution turned <b>purple inside</b>	9	
- <b>Baggie</b> was <b>impermeable</b> to <b>starch</b> because solution <b>remained inside</b> the bag; evidence was that <b>no color change</b> occurred <b>outside</b>	3	
2. Potato in salt size <b>decreased</b> because <b>water</b> moved <b>out</b> (potato was <b>hypotonic</b> to salt solution)	4	
Potato in water size <b>increased</b> because <b>water</b> moved <b>in</b> (potato was <b>hypertonic</b> to water)	4	
3. Egg in water <b>swelled</b> because <u><b>water moved in</b></u> from <b>high to low</b> through process of <b>osmosis</b> (egg was <b>hypertonic OR solution hypotonic</b> )	5	
Egg in syrup <b>shrank</b> because <u><b>water moved out</b></u> from <b>high to low</b> through process of <b>osmosis</b> (egg was <b>hypotonic OR solution hypertonic</b> )	5	
	51	

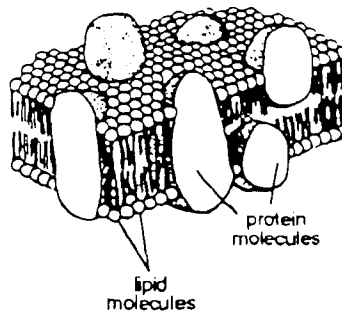
TOTAL POSSIBLE:

/75

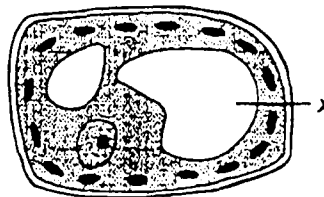
## APPENDIX D. CELLS TEST FORM A (CHAPTER 4)

Name \_\_\_\_\_

- 1) According to the cell theory, which statement is correct?
- A) Viruses are true cells. ☐ Cells come from preexisting cells.  
 B) Mitochondria are found only in plant cells. ☐ Cells are basically unlike in structure.
- 2) Microscopic examination of an animal cell reveals the presence of a plasma membrane but no cell wall. Which additional structures would normally be present within this cell?
- ☒ A) centrioles ☐ B) chloroplasts ☐ C) large vacuoles ☐ D) starch grains
- 3) Which cell organelles are the sites of aerobic cellular respiration in both plant and animal cells?
- A) chloroplast ☐ B) centrosomes ☐ C) nuclei ☒ D) mitochondria
- 4) Which cellular organelle is represented by the diagram below?



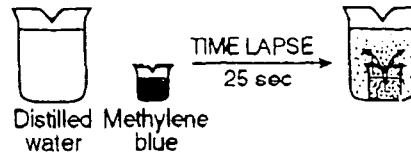
- A) centriole ☒ B) plasma membrane ☐ C) ribosome ☐ D) cell wall
- 5) Which statement best describes the plasma membrane of a living plant cell?
- A) It has the same permeability to all substances found inside or outside the cell.  
 B) It is composed of proteins and carbohydrates only.  
☒ C) It selectively regulates the passage of substances into and out of the cell.  
 D) It is a double protein layer with floating lipid molecules.
- 6) Which process requires the expenditure of cellular energy?
- A) osmosis ☒ B) active transport ☐ C) diffusion ☐ D) passive transport
- 7) Human red blood cells placed in a 2% salt solution appear to shrink, but those placed in a 0.4% salt solution burst. Which statement best supports these observations?
- A) The nucleus does not regulate water balance in a cell.  
 B) Salt is actively transported across cell membranes.  
☒ C) Salt causes cell walls to swell.  
☒ D) Osmosis may occur in either direction across the cell membrane.
- 8) In the diagram of a cell below, the structure labeled X enables the cell to



- A) release energy ☐ C) manufacture proteins  
☒ B) store waste products ☐ D) control nuclear division



- 9) A student was given a beaker containing distilled water and a separate smaller beaker containing a solution of methylene blue. The student was directed to carefully lower the smaller beaker into the larger beaker. He observed that the methylene blue began to disperse into the distilled water, as shown in the diagram below.



Which process was most likely responsible for the observed changes?

- A) pinocytosis      B) osmosis      ☒ C) diffusion      D) active transport
- 10) Molecules that are too large to pass through the pores of a cell membrane may enter the cell by a process known as
- A) synthesis      ☒ B) pinocytosis      C) cyclosis      D) hydrolysis

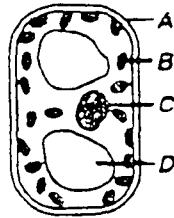
### Essay Questions-A

- 1 Describe the fluid-mosaic model of a plasma membrane. Discuss the role of the membrane in the movement of materials through by both active and passive transport.
- 2 A laboratory assistant prepared solutions of 80%, 60%, 40%, and 20% sucrose but forgot to label them. After realizing the error, the assistant randomly labeled the flasks containing these four unknown solutions as flask A, flask B, flask C, and flask D. Design an experiment, based on the principles of diffusion and osmosis, that the assistant could use to determine which of the flasks contains each of the four unknown solutions.
- 3 Describe the structure of a generalized eukaryotic plant cell. Explain the ways in which a nonphotosynthetic prokaryotic cell would differ in structure from this generalized eukaryotic plant cell.
- 4 Compare and contrast a plant cell (onion cell) and an animal cell (human cheek cell). Include at least 3 comparisons in your answer.

## APPENDIX E. CELLS TEST FORM B (CHAPTER 4)

Name: Scy B

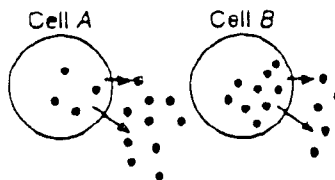
- 1) Which statement describes an exception to the cell theory?
- A) The cell is the basic unit of structure in plants.
  - B) Cells arise from previously existing cells.
  - ☒ C) Mitochondria and chloroplasts can reproduce within the cell.
  - D) The cell is the basic unit of function in animals.
- 2) Which organelle is present in the cells of a mouse but not present in the cells of a bean plant?
- A) cell membrane
  - B) chloroplast
  - C) cell wall
  - ☒ D) centrosome
- 3) Most cellular respiration in plants takes place in organelles known as
- A) stomates
  - ☒ B) mitochondria
  - C) chloroplasts
  - D) ribosomes
- 4) Most cell membranes are composed principally of
- A) chitin and starch
  - B) nucleotides and amino acids
  - ☒ C) proteins and lipids
  - D) DNA and ATP
- 5) The net movement of molecules into cells is most dependent upon the
- A) number of chromosomes
  - B) selectivity of the cell wall
  - C) number of nucleoli
  - ☒ D) selectivity of the plasma membrane
- 6) Which process would include a net movement of sugar molecules through a membrane from a region of lower concentration to a region of higher concentration?
- ☒ A) active transport
  - B) passive transport
  - C) osmosis
  - D) cytokinesis
- 7) A red blood cell placed in distilled water will swell and burst due to the diffusion of
- ☒ A) water into the red blood cell
  - B) salt from the red blood cell into the water
  - C) water from the red blood cell into its environment
  - D) salts from the water into the red blood cell
- 8) The diagram below represents a plant cell.



Which cell structure functions as a storage site for organic acid wastes?

- A) A
- B) B
- C) C
- ☒ D) D

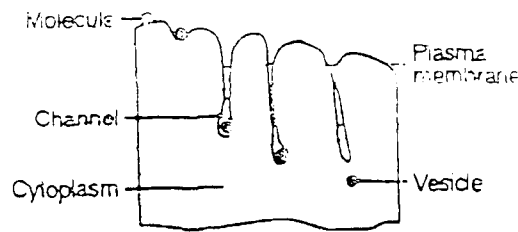
- 9) The arrows in the diagrams below represent the direction of movement of a certain type of molecule through the cell membrane of two different cells. The dots represent the relative concentrations of this molecule.



Which processes are illustrated in the diagrams?

- A) pinocytosis and osmosis
- B) phagocytosis and diffusion
- C) dehydration synthesis and circulation
- ☒ D) active transport and diffusion

- 10) The diagram below shows the method of entry of a molecule too large to diffuse through the plasma membrane of a cell.



The process represented in the diagram above is known as

A) osmosis

B) homeostasis

C) cyclosis

☒ D) pinocytosis

### Essay Questions-B

1. Membranes are important structural features of cells. Describe how membrane structure is related to the transport of materials across a membrane using both active and passive transport.
2. Flasks X, Y, and Z contain solutions with different concentrations of the solute NaCl. Flask X has 0.5% NaCl, flask Y has 0.9% NaCl, and flask Z has 1.5% NaCl. Red blood corpuscles (0.9% NaCl) were placed in each flask, but unfortunately the lab assistant forgot to label the flasks. Explain how you could determine the concentration of NaCl in each of the unknown flasks.
3. Describe the structure of a prokaryotic bacteria cell and explain how it differs in structure from an eukaryotic onion skin cell.
4. Compare and contrast the cells of spinach (plant cells) and the cells of dogs (animal cells). Include at least 3 comparisons in your answer.